AEDC-TR-84-10
C.3

# Initial Feasibility Ground Test of a Proposed Photogrammetric System for Measuring the Shapes of Ice Accretions on Helicopter Rotor Blades During Forward Flight



Richard L. Palko and Patrick L. Cassady
Calspan Field Services, Inc.
and
Robert C. McKnight and Robert J. Freedman
NASA-Lewis Research Center
Cleveland, Ohio

August 1984



Final Report for Period 1 October to 31 December 1983

Approved for public release; distribution unlimited.

ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

## APPROVAL STATEMENT

This report has been reviewed and approved.

Marshall K. Kingery

MARSHALL K. KINGERY
Directorate of Technology
Deputy for Operations

Approved for publication:

FOR THE COMMANDER

Marion L. Laster

MARION L. LASTER
Director of Technology
Deputy for Operations

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a REPORT SECURITY CLASSIFICATION: Unclassified | 1b RESTRICTIVE MARKINGS |
| 2a SECURITY CLASSIFICATION AUTHORITY | 3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited. |
| 2b DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A | |
| 4 PERFORMING ORGANIZATION REPORT NUMBER(S): AEDC-TR-84-10 | 5 MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a NAME OF PERFORMING ORGANIZATION: Arnold Engineering Development Center; 6b OFFICE SYMBOL (If applicable): DOT | 7a NAME OF MONITORING ORGANIZATION |
| 6c ADDRESS (City, State and ZIP Code): Arnold Air Force Station, TN 37389 | 7b ADDRESS (City, State and ZIP Code) |
| 8a NAME OF FUNDING/SPONSORING ORGANIZATION: U.S. Army Research; 8b OFFICE SYMBOL (If applicable): DADL-ATL-ASR | 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER |
| 8c ADDRESS (City, State and ZIP Code): Fort Eustis, VA 23604 | 10 SOURCE OF FUNDING NOS. |

| PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. | WORK UNIT NO. |
|---|---|---|---|
| 921C12 | DA43PW | | |

11 TITLE (Include Security Classification): Initial Feasibility Ground Test of a

12 PERSONAL AUTHOR(S): Palko, Richard L. and Cassady, Patrick L., Calspan Field Services, Inc./AEDC;

| 13a TYPE OF REPORT | 13b TIME COVERED | 14 DATE OF REPORT (Yr., Mo., Day) | 15 PAGE COUNT |
|---|---|---|---|
| Final | FROM 831001 TO 831231 | 1984 August | 43 |

16 SUPPLEMENTARY NOTATION: Available in Defense Technical Information Center (DTIC).

17 COSATI CODES

| FIELD | GROUP | SUB. GR. |
|---|---|---|
| 01 | 03 | |
| 01 | 04 | |

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number): stereophotogrammetry, stereophotography, ice formation, rotor blades, control system

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A ground test was accomplished to determine if a combination of standard photographic system parameters could be chosen that would allow stereophotographs to be made of the main rotor of a UH-1H helicopter in forward flight. The photographs would be used to measure the shape of ice accretions on the rotor in forward flight. During the ground test, 83 photographic pairs were obtained at three camera shutter speeds for a range of ambient light conditions from dark to complete daylight. Twenty-seven of these photographic pairs were evaluated on the AEDC analytical stereocompiler for readability. The test showed that quality photographs could be taken using standard equipment with shutter speeds of 1/30 and 1/60 sec for up to three hours per day. The test also showed that the addition of a specially designed control circuit for synchronization at 1/500-sec shutter speed would allow testing for the complete day for most winter days.

| | |
|---|---|
| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☒ DTIC USERS ☐ | 21 ABSTRACT SECURITY CLASSIFICATION: Unclassified |
| 22a NAME OF RESPONSIBLE INDIVIDUAL: W. O. Cole | 22b TELEPHONE NUMBER (Include Area Code): (615) 455-2611, Ext. 7813; 22c OFFICE SYMBOL: DOS |

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

Block 8a. (Concluded)

Technology Laboratory AVRADCOM

Block 11. (Concluded)

Proposed Photogrammetric System for Measuring the Shapes of Ice Accretions on Helicopter Rotor Blades During Forward Flight. (U)

Block 12. (Concluded)

and McKnight, Robert C. and Freedman, Robert J., NASA-Lewis Research Center, Cleveland, Ohio

## PREFACE

The work reported herein was conducted jointly by the National Aeronautics and Space Administration Lewis Research Center (NASA LeRC), Cleveland, Ohio, under NASA Project Number YOM 2734, and the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Air Force Control Number 9C12. The AEDC effort was funded by the U. S. Army Applied Technology Laboratory (ATL) with Michael F. Rose as project monitor. The AEDC work was conducted by Calspan Field Services, Inc./AEDC Division, operating contractor for the aerospace flight dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The Air Force project manager was Marshall K. Kingery, AEDC/DOTS, and the AEDC Project Number was DA43PW (Calspan Project Number P32L-CW). The work was performed during the period from 1 October to 31 December 1983. The manuscript was submitted for publication on March 8, 1984.

The authors wish to express their appreciation to John P. Greissing and William Wildenheim, LeRC, for their valuable assistance during the test setup and to Major Robert Roffi, U. S. Army Reserve, Facility Supervisor, AFA No. 14, and his unit at Lorain County Airport, Elyria, Ohio, who supplied the facility and helicopter for the ground test.

The authors wish to give special recognition to CW4 Gary Smith, U. S. Army Reserve, Pilot and Chief of Aircraft Maintenance, AFA No. 14, who assisted in designing the test, supervised the test support activities of AFA No. 14, and operated the helicopter during the test.

## CONTENTS



## ILLUSTRATIONS

## TABLES

# 1.0 INTRODUCTION

AEDC and NASA LeRC first used stereophotogrammetry for measuring helicopter blade ice accretions in a joint U. S. Army/NASA hover-flight icing test program during the 1983 fiscal year. The flight program was conducted with a U. S. Army UH-1H helicopter at the Canadian National Research Council Spray Rig in Ottawa, Canada, during January and February of 1983. The purpose of the test was to relate the aerodynamic performance degradation of the helicopter to ice buildup on its main rotor.

One phase of the test program was to determine the shape of the ice buildup on the main rotor of the helicopter that produced the performance degradation. This data will be used to develop computer codes for prediction of helicopter performance in various icing conditions. Two methods of determining the ice shape were used: (1) impression molding and (2) stereophotogrammetry. For this study the helicopter was hovered in an ice cloud produced by the spray rig until the desired ice buildup was acquired. Then, the helicopter was landed, and the stereophotographs and mold impressions were obtained. Both methods gave good results.

Although the hover-flight test produced some useful data, a more significant case is the ice accretion process and performance degradation during forward flight. Before impression molds could be made of the ice shape from a forward-flight condition, it would require flying in the icing cloud to obtain the ice buildup and then taking performance measurements; the helicopter must then fly to the molding station, land, and the rotor brought to a stop. During all the time and maneuvering needed after leaving the icing cloud, the ice could be sublimating or shedding from the main rotor, thus making the results questionable. If a method of obtaining the ice shape immediately after coming out of the ice cloud (or during or after the performance measurement) could be developed, it would minimize the effects of sublimation or shedding.

The stereophotogrammetry used during the hover-flight icing test would provide such a method if a high-speed photography technique could be developed to photograph the main rotor in motion. This would permit photographs to be taken immediately before, during, and after the performance-loss measurements were made, and then later the photographs could be analyzed on the analytical stereocompiler to obtain the ice shapes. Recognizing that such a technique would provide significant data for the development of the computer prediction codes, a joint effort was undertaken between NASA-LeRC and AEDC. Advancing to inflight stereophotography of a rotating blade will require considerably more complexity and development than photographing a stationary blade. Therefore, the project was divided into sequential phases. Phase 1 is for development and ground testing of the basic photography and formation station-keeping equipment and procedures. This phase will culminate with ground test simulation of the flight situation. Once the system elements are developed so that their feasibility to produce suitable results is proven, Phase II will follow with proof-of-concept flight tests.

This report covers the work accomplished on Phase I between 1 October and 31 December 1983.

## 2.0 APPROACH

Several items must be considered in the development of a system that will provide photographs with the required resolution for accurate stereoanalysis. These items include, but are not limited to the following: the control points, camera positioning platform, photography system (cameras, lenses, light source, etc.), and control system.

### 2.1 CONTROL POINTS

Since the data obtained from stereophotographs can be no better than the control data used in the analysis, the method of providing control points was one of the first items considered. In analyzing stereophotographs it is necessary to have a minimum of six control points, for which the Cartesian coordinates are accurately known, visible in both pictures. However, better results are obtained when about 15 control points are used. Normally, 25 to 30 points are installed to allow for losses and light reflections during testing. All of the control points cannot be located in the same plane and should, for best results, surround the measurement area. The control points must also be located on a surface that will not change shape or change position of the points (relative to each other) after their locations have been determined.

One way to provide control points on an airfoil is the method used on the NASA-LeRC DHC-6 Twin Otter. This method utilizes control points located on the wing fence and along the airfoil near the fence. The control points along the airfoil are placed far enough aft of the leading edge to avoid becoming iced over. This method will be used for the feasibility study. The method assumes that for short spans (in the neighborhood of 3 or 4 ft) the rotor deflection will be small. In the final flight configuration, multiple fences may be required to cover the rotor span, while for the feasibility study and flight demonstration, only one will be used. An example of the proposed control point layout is shown in Fig. 1. For structural purposes it may be necessary to carry the fence all the way to the trailing edge of the blade; however, for control point purposes this would not be required. Some variation in control point position tolerances may be required for the points farthest from the fence. The variation of the ice thickness on the main rotor during one of the hover-flights is shown in

Fig. 2. The area that could be analyzed with the control point locations of Fig. 1 is shown in Fig. 2. The primary and secondary analysis areas with the fence located at the 17-ft spanwise station are shown in Fig. 2.

## 2.2 CAMERA POSITIONING PLATFORM

The second item that had to be considered was the camera positioning platform. Obviously this had to be some type of airborne system that would give the correct distance between the cameras, the angle toward the blade, and the angle to the fence (or fences). For maximum accuracy, the base between the cameras should be equal to the distance from the subject with the cameras angled in toward the subject. However, for ease of reading, it is better to have the cameras mounted parallel to each other and positioned to give approximately 60-percent overlap of the exposures from the two cameras. For a combination of accuracy and ease of reading, a base between the cameras equal to one-half the distance to the subject has been found to give good results. The angle of the cameras toward the blade (top or bottom) must be such that the control points along the blade, as well as the area where the ice has accumulated, are clearly visible. Finally, the angle of the cameras to the fence must be such that the control points on the fence are clearly visible. From past experience, the minimum angle that should be considered is 15 deg.

The first consideration was to place the cameras on the test helicopter; however, after careful examination, it was determined that no suitable locations for overlapping stereo-cameras were available. An alternative was to use a second flight vehicle flying in a stand-off formation as the camera platform. Since the NASA-LeRC DHC-6 Twin Otter flight envelope and physical size match the type of vehicle needed as a camera platform, it was selected as the vehicle for the feasibility study.

The first flight-formation concept considered would have the cameras mounted in pods at the wing tips and called for the DHC-6 Twin Otter to be flown behind the test helicopter and slightly to one side, either above or below depending on the photographs desired. This concept is shown in Fig. 3. Although this concept would give good camera view geometry, another more practical formation concept was selected after consulting with the U. S. Army Aviation Engineering Flight Activity (AEFA), which routinely flies formation on test helicopters with a fixed-wing aircraft. With the selected concept, the DHC-6 Twin Otter is flown abeam the test helicopter at a station where the main rotor blades are viewed in the position shown in Fig. 4. The horizontal separation between the tip of the main rotor and the wing tip would be 30 ft and the vertical separation about 10 ft. This is within the separation criteria used by AEFA. With this concept, the cameras can be located in the Twin Otter's forward and aft baggage compartments, shown in Fig. 5, giving a stereo base separation distance of approximately 35 ft. This formation position gives the desired camera base distance-to-subject distance required for the photo analysis. It also gives an upward-looking angle of about 10 deg which, from the hover-flight icing tests was determined to be the optimum angle. It provides a good positioning reference for the pilot during the photography sequence and a good angle between the aft camera and the fence on the main rotor. (The front camera has an even better angle.)

## 2.3 PHOTOGRAPHY SYSTEM

Several things must be considered in the selection of a photographic system (cameras, lenses, light source, etc.) that will produce photographs, with good resolution, of an 8-ft section of a helicopter main rotor that is moving at approximately 550 ft/sec. To understand the magnitude of the problem, computations show that an exposure time of 17 $\mu$sec (1/64,000 sec) is required to stop the blade section's motion to $\approx$ 1/8 in. during the exposure. (This would probably give the maximum blurr in the photographs that could be tolerated in reading ice formations with the stereocompiler.) It is immediately obvious that a standard shutter in ambient daylight is not practical. The easiest solution would be to fly at night and use a strobe flash with a 17-$\mu$sec pulse to stop the rotor motion. However, the flying of night formation with the three aircraft that would be required (test helicopter, spray-tanker helicopter, and photographing airplane) is very undesirable, at best. The next thing considered was to use some type of high-speed shutter such as a rotary or PLZT. Study of these types of shutters showed that synchronization of the rotary shutters and the helicopter rotor would be very difficult and that the PLZT shutters will only pass 20 percent of the light. Therefore, both types of shutters were dropped as viable options, and a third option was selected for the feasibility study. This option would use a combination of ambient light, strobe flash, shutter speed, f/stop, and film speed all matched to permit flying in safe ambient light with still enough contrast to obtain usable photographs. The exact combination of these parameters would be determined with a preliminary ground test.

Currently, 70-mm Hasselblad® cameras are used for all stereophotogrammetric analysis at both AEDC and NASA-LeRC. However, the AEDC analytical stereocompiler that is used to do the analysis for both organizations is sized to take up to a 9- by 9-in. format. To take advantage of the 9- by 9-in. format that would give more tolerance in aiming the cameras and still have the same resolution that is obtainable with the 70-mm cameras, attempts were made to locate aerial cameras with a 9- by 9-in. format. It was discovered that there are no 9- by 9-in. aerial cameras in the AFSC inventory, and efforts to borrow cameras outside of AFSC were unfruitful. The decision was then made to use the existing NASA 70-mm Hasselblad cameras for the feasibility study. Two new 500-mm lenses were procured for the test. (These are the longest that Hasselblad makes.) The flash power source used was furnished by AEDC. This power source utilizes four capacitors, each capable of storing 500 wsec of energy. The system can be wired to use from one to four capacitors at a time, thus giving a maximum of 2000 wsec if desired. Four xenon flash tubes were used in parallel to shorten the discharge time. This flash system was calibrated using an EG & G Lite-Mike® and a storage scope with the four-capacitor configuration. Typical traces from the calibration are shown in Fig. 6 and show that the flash pulse was between 20- and 25-$\mu$sec long depending on whether one uses one-half or two-thirds peak as the measure.

### 2.4 CONTROL SYSTEM

With the selected photography concept, the function of the control system is to synchronize the position of the rotor, lens opening, and strobe flash. With a flight configuration, part of the system would be located onboard the test helicopter, and part would be located onboard the photography airplane (DHC-6 Twin Otter). A diagram of the control concept is shown in Fig. 7. With this system, a signal bracket is mounted to the rotating swashplate, and a magnetic pickup is mounted to the stationary swashplate of the helicopter. (This is standard flight hardware used by the U. S. Army for blade tracking tests.) The signal from this pickup is amplified and fed into a delay circuit that can be adjusted to delay the signal between zero and the time of one shaft revolution. Each revolution of the shaft sends a new signal. The delayed signal from the delay circuit is fed into the camera start circuit. When the enable switch is depressed, the camera start circuit takes the next pulse from the delay circuit as the start signal and sends it to the camera control which triggers the camera shutter. When the shutter of the slowest camera is completely open, it sends a signal to the flash power supply which in turn triggers the flash. With a flight system, the amplified rotor position signal will be transmitted from the helicopter to the airplane, and the flash signal will be transmitted from the airplane to the helicopter. During the preliminary ground test, the system was hard-wired together.

## 3.0 PROCEDURE

To verify that quality stereophotographs can be made of a helicopter main rotor that is turning at 325 rpm ($\approx$ 550 ft/sec at the spanwise stations of interest) and that 70-mm Hasselblad cameras with 500-mm lenses are adequate, a preliminary ground test was conducted at the Lorain County Airport, Elyria, Ohio.

### 3.1 TEST HELICOPTER

The test helicopter was a U. S. Army Reserve UH-1H from AFA No. 14. A single-wiper bracket from a Chadwick-Helmuth Strobex© rotor signal generator (normally a double- and a single-wiper bracket are installed opposite each other), of the type used by the U. S. Army for inflight blade-tracking tests was installed on the rotor heads' rotating swashplate, and the magnetic pickup was mounted to the stationary swashplate. The installation of the rotor signal generator is shown in Fig. 8.

For the feasibility test, including the flight demonstration, it will be necessary to have the fences (one on each blade) and control points installed on the main rotor. However, since the helicopter used for the preliminary ground test was borrowed, it was not possible to have any modification made that could not be easily removed. Therefore, it was necessary to put some type of markings on the rotor that would permit evaluation of the photographic quality and still be easily removed after the test. The method used was to put strips of 3-in. wide yellow tape around the blades at 1-ft distances starting at the 12-ft (50-percent radius) spanwise station and extending out to the 20-ft (83-percent radius) spanwise station. Commercially available rub-on targets were then applied to the tape around the leading edge of the blade back to approximately one-quarter chord. The technique of applying the tape and examples of the targets are shown in Fig. 9. Photographs of the main rotor with the tape applied are shown in Fig. 10.

### 3.2 PRELIMINARY CONTROL SYSTEM

The concept for the control system to be utilized in flight is shown in Fig. 7 and described in Section 2.4. This system would be custom-built and packaged for minimum weight and size. However, for the preliminary ground test the weight and packaging were not a factor. The main consideration was to have a system that would work similar to a flight system, but with minimum effort to put it together. Therefore, the majority of the system consisted of equipment that was already available at NASA-LeRC or AEDC. The system was made up with a rotor position indicator borrowed from a U. S. Army National Guard helicopter unit; a Preston® amplifier, angle clock, and camera control system (including the vacuum control system) from NASA-LeRC; and the flash system (including power supply and flash tubes) from AEDC. The only circuit that was fabricated specifically for the test was the starting circuit. A wiring diagram of the starting circuit and how it interfaces with the control system is shown in Fig. 11. The overall system was basically the same as the concept shown in Fig. 7 with hard-wiring replacing the transmitters and receivers.

### 3.3 TEST SETUP

For the test setup, the helicopter was positioned on the ramp facing west so that when the cameras were focused on the retreating blade they were looking south. The cameras were mounted on stands so that they could be located at the approximate position they would be in for the flight test in distance-from-subject, separation, and elevation. The cameras were located at two different positions as shown in Fig. 12. The 85-ft position represents the flight position for the 500-mm lens used for the test, and the 60-ft position, using the 500-mm lens, simulates the flight position of 85-ft when using an 800-mm lens.

Since the flash intensity on the rotor surface decreases with the square of the distance to the flash source, it is necessary for the flash heads to be mounted on the helicopter close to the blade. The area over the engine cowling was selected as the best overall mounting location for the flash-to-subject distance and grazing angle. To simplify the test setup, the flash heads were mounted on a platform that was cantilever-mounted off an elevated work stand. The stand was located next to the helicopter on the left side so that the flash heads were over the engine cowling and facing along the seven-o'clock blade position. The flash power supply was located on the ramp at the right side of the helicopter and abeam the flash heads. The helicopter, power supply, and flash heads are shown in Fig. 13.

As stated earlier, the cameras were mounted on stands to position them in the simulated flight position. The mounting plates on the stands could be adjusted to give the needed angle of inclination as well as elevation. One major problem with the Hasselblad camera is that the speed of the mechanical part of the shutter starting mechanism is very temperature-sensitive and will usually quit working at temperatures below 40°F. Therefore, since the temperature during the test would be below freezing (the actual temperature during the test was 27°F), heating blankets were placed over the cameras. These heating blankets proved to be inadequate, and a hot-air blower was used in conjunction with the heating blankets to keep the cameras at the required operating temperature. The left camera (C1), mounting stand, and heating system are shown in Fig. 14.

The control circuit equipment was located on a cart so that it could be easily positioned during the setup. The communication between the various personnel involved with the test was accomplished through headsets plugged into the helicopter intercom system. The general arrangement and hookup of the equipment is shown in Fig. 15.

### 3.4 TEST PROCEDURE

During the test the helicopter was operated at flat pitch and normal (325) rpm. Once the pilot had the rotor on speed and gave the order to proceed, the camera control system and flash power system were both setup for operation. When all systems were up and operating, the camera operator requested the flash power operator to charge the flash system. When the system was ready, a red light would appear on the flash power control console which was visible at the camera control station. When the light appeared, the camera operator would then start the automatic camera shutter and flash control sequence. This procedure was repeated for each stereophoto pair taken. The first shots of each test sequence were used to adjust the delay circuit until the blade position and flash were synchronized to give the proper blade orientation (approximately the seven-o'clock position). This daily adjustment to the delay circuit was necessary because of the sensitivity of the cameras to temperature and the inability to adjust the crude heating system to be the same each day. It was easier to make minor adjustments to the delay circuit.

Three test sequences were made. The first was strictly a night test and was used to set up the system and to select the flash power intensity. The second sequence started just before official sunrise and ran until approximately one hour after sunrise. The third sequence started approximately 30 min before official sunset and ran until approximately one hour after sunset. A total of 83 stereo photo pairs were taken. The test log, which details the important test variables, is shown in Table 1. The ambient light intensity was determined using a Weston® light meter and then converted to fc using Fig. 16.

## 4.0 RESULTS AND DISCUSSION

The analysis of the stereophotographs was performed with the AEDC stereophotogrammetric analysis system. This system is built around a K & E DSC-3/80® analytical stereocompiler. The application of this system is reported in Ref. 1. Twenty-seven of the 83 photographic pairs were analyzed. The analysis was made by placing each of the selected pairs on the analytical stereocompiler and determining the following information: (1) readability based on both motion and ambient light and (2) spanwise distance along the blade from which icing data could be read. Both determinations are compiler-operator judgment from past experience in analyzing icing data and are based on the clarity of the targets on the yellow strips. Each strip represents an additional foot of rotor span starting with the first strip at the 50-percent radius station (12 ft from the hub) and ending with the ninth strip at the 83-percent radius station (20 ft from the hub). A typical photographic pair is shown in Fig. 17. The results of the evaluation made using the stereocompiler are summarized in Table 2.

The objective of the preliminary ground test, as stated in Section 2.3, was to determine the exact combination of photographic system parameters that are required to obtain usable photographs for stereoanalysis. These parameters were (1) ambient light, (2) strobe flash (intensity and time), (3) shutter speed, (4) f/stop, and (5) film speed. The small format size (70 mm) of the cameras and the large magnification of the analytical stereocompiler used in the analysis made it necessary to stay with a slower film speed; therefore, Kodak Ektachrome® 64 was selected. The photographs taken during the first test sequence (Table 1, 11/17/83, Exp. No. 12) revealed that maximum aperture is required with the 500-mm, f/8 Hasselblad lens and that maximum flash intensity (Table 1, 11/17/83, Exp. No. 15) is required. Although, both of these photo pairs were analyzed on the stereocompiler after the test, the conclusions were obvious with a magnifing glass as soon as the film was developed, and these variables were fixed at that point. Therefore, only two parameters were left to vary during the remaining test sequences: ambient light and shutter speed.

Although past experience has shown that synchronization of two Hasselblad cameras with a flash unit that is synchronized off of only one camera while using a single starting source is usually not dependable at shutter speeds greater than 1/30 sec, data were obtained at shutter speeds of 1/30, 1/60, and 1/500 sec through the change in ambient light from dark to full sunlight. Of course, as was expected, the only exposures obtained with the 1/500-sec shutter speed were from the camera that was used to synchronize the flash. However, somewhat surprising, all of the exposures taken with the 1/60-sec shutter speed settings were synchronized with both cameras. The reason for trying the 1/500-sec settings was to determine if either the quality of exposures or the extended daylight time limit that might be obtained would be worth the cost and effort of the circuit that would be required to synchronize the cameras at 1/500-sec shutter speed.

The analysis of the photographs revealed the following results. Based on a pilot's observations, a conservative ambient light level for safe research formation flight with the helicopter was approximately 3-fc intensity. This condition occurred approximately 10 min after official sunset on an overcast (5000-ft) day. With the 1/30-sec shutter speed settings, the maximum ambient light that could be tolerated during exposure would be somewhere between 73 and 290 fc. (The photographs taken at 73-fc light intensity were readable, whereas, the photographs taken at 290-fc light intensity were not readable.) On a sunny day, this would give about two hours during which testing could be accomplished, one hour in the morning and one hour in the evening. On an overcast day, the testing time would be increased; however, the extent of the increase was not measured during the test. With the 1/60-sec shutter speed settings, the maximum ambient light that could be tolerated during exposure moved up enough to extend the time (on a sunny day) at least 30 min at both ends, giving a minimum of three hours of testing per day. Again, on an overcast day, the test time would be increased. The 1/500-sec shutter speed gave the best exposures by far for stereocompiler analysis, and the quality of the exposures was good up to the maximum ambient light for which test photographs were taken, which was approximately 1160 fc. This is considerably under the ambient light intensity for a day with sun out, scattered clouds over snow, which was measured at one o'clock in the afternoon at an intensity of 7000 fc. However, it is not that far from the maximum light intensity that was measured at twelve o'clock noon on a day with scattered clouds at 1800 ft with an overcast at 7000 ft and six miles visibility, which was found to be 1750 fc.

A comparison between a photograph taken at a shutter speed of 1/30 sec with an ambient light intensity of approximately 75 fc and a photograph taken at a shutter speed of 1/500 sec with an ambient light intensity of approximately 1160 fc is shown in Fig. 18. The exposure taken at 1/30 sec is very nearly the limit in ambient light intensity that can be tolerated and still give a readable photograph. However, the exposure taken at 1/500 sec could still tolerate a considerable amount of ambient light before becoming unreadable. Therefore, it is believed that if discretion is used when considering the direction the aircraft are headed (cameras are aimed in relation to the sun), the limiting factor on testing with a

1/500-sec exposure capability would be pilot visibility at dawn and dusk and not the ambient light intensity during daylight hours.

An additional consideration that had to be addressed was the tolerance that must be held during the formation flying to have the cameras remain in focus. According to the manufacturer's specifications for the 500-mm lens, the depth-of-field at 85 ft with an f/stop of 8 is 15 ft. To check this, photographs with the blade at 4, 6, and 8 o'clock positions were examined. At the 50-percent (12-ft) spanwise station, the distance change between the four o'clock and eight o'clock positions is approximately 20 ft, or 10 ft on either side of the six-o'clock position. The examination of the photographs showed that the pictures taken at the six- and eight-o'clock positions were both still in focus; however, the picture from the four-o'clock position was beginning to get out of focus. The conclusion made from the examination was that if the formation can be maintained within the manufacturer's specifications (15 ft), the photographs should remain in focus. It is believed that, with a separation distance of only 30 ft between blade tip and wing tip, the formation should beheld to within ±5 feet.

The photographic evaluation, both from the exposure quality and the extended test time, shows that the development of a special synchronization circuit is worth the time and cost. Preliminary evaluation of the circuit requirements were made which indicate that the addition of a second delay circuit will accomplish the desired results. A diagram of the new proposed control circuit is shown in Fig. 19. With this circuit, Delay No. 1 is equal to the time it takes for the blade to rotate from the detector position to the required position for the stereophotographs, minus the time it takes to open the shutter to full open for the slowest camera. Delay No. 2 is equal to the difference in the speeds of the shutter mechanical systems of the two cameras. Because of the sensitivity of the camera operating speed to temperature, camera enclosures that can be temperature-controlled should be developed. Care should be taken to keep the enclosures at the same temperature at which the synchronization was accomplished.

## 5.0 SUMMARY AND RECOMMENDATIONS

A ground test was accomplished to determine if a combination of standard photographic system parameters could be chosen that would allow stereophotographs to be made of the main rotor of a UH-1H helicopter in forward flight. The photographs would be used to measure the shape of ice accretions on the rotor in forward flight. During the ground test, 83 photographic pairs were obtained at three camera shutter speeds (1/30, 1/60, and 1/500 sec) for a range of ambient light conditions from dark to complete daylight. Twenty-seven of these photographic pairs were evaluated on the AEDC analytical stereocompiler for readability. The test showed that quality photographs could be taken using standard equipment with shutter speeds of 1/30 and 1/60 sec for up to three hours per day. The test also showed that the addition of a specially designed control circuit for synchronization at 1/500-sec shutter speed would allow testing for the complete day for most winter days.

It is recommended that the new control circuit be developed to allow synchronization of the cameras, flash, and helicopter rotor at fast shutter speeds. The system should be packaged for flight tests, including radio transmitters and receivers. The system should be completely checked on the ground including the transmitting circuitry. During the ground test, a more complete analysis should be made to determine the maximum ambient light intensity that can be tolerated with the 1/500-sec shutter speed. This would avoid testing when the ambient light intensity is too high. In addition to the new control circuit, the fences should be installed on the rotor so that the readability and accuracy of the control points can be established with the analytical stereocompiler. After the ground checkout is completed, the system should be flight-tested for reliability and to establish the formation flying techniques that will be required to obtain the data. All of this should be completed prior to the icing season.

## REFERENCES

1. Palko, Richard L. and Cassady, Patrick L. "Photogrammetric Development and Application at AEDC." Paper No. 82-0610, AIAA 12th Aerodynamic Testing Conference, Williamsburg, VA, March 21-24, 1983.

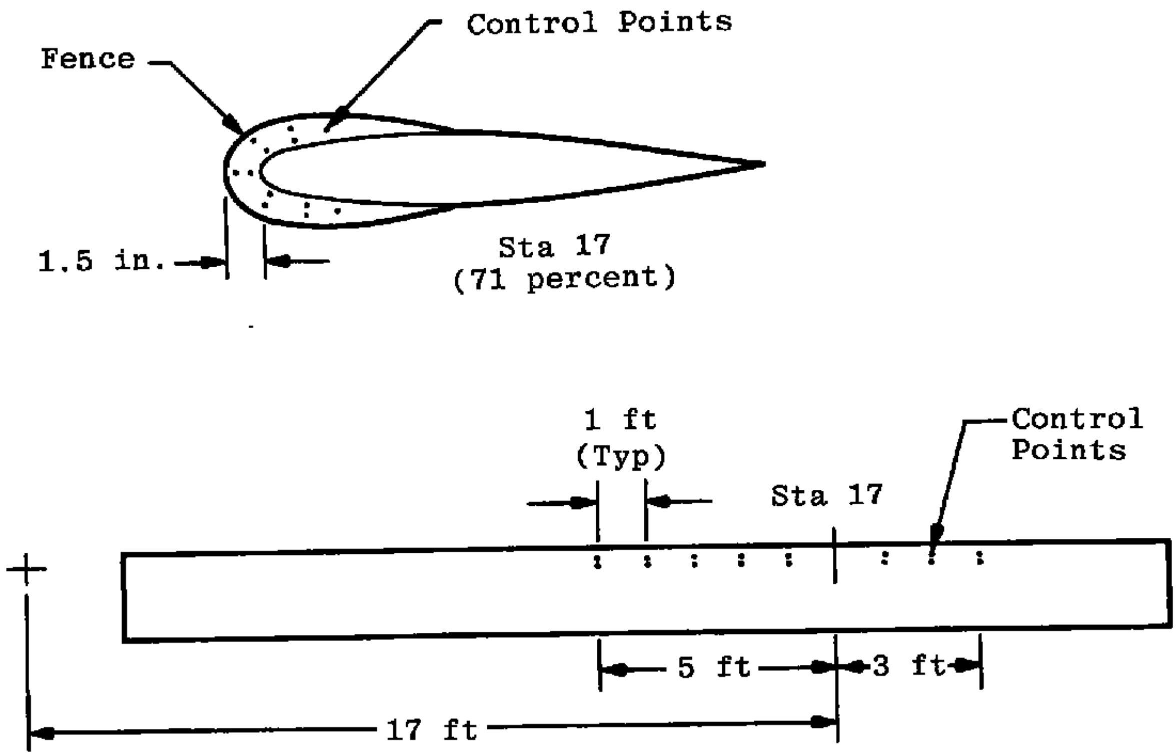



**Figure 1. Control point system.**

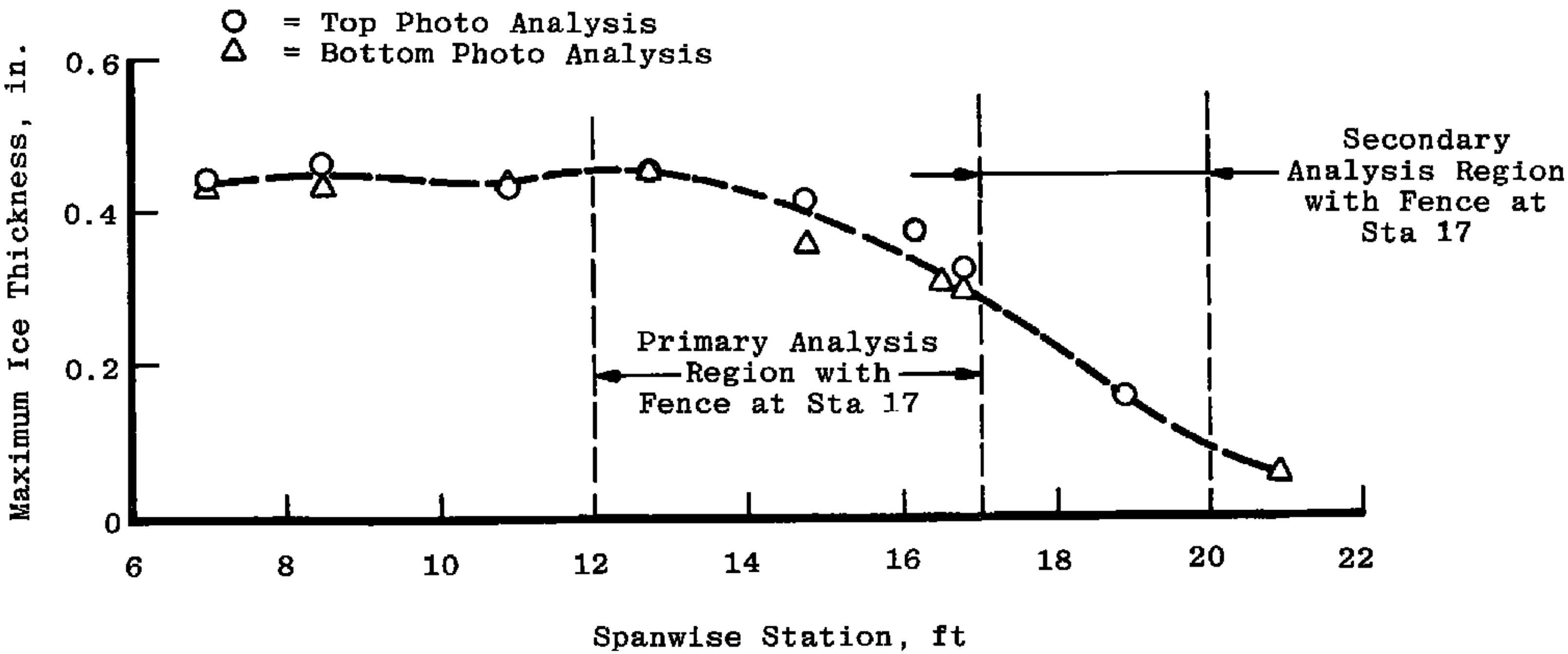
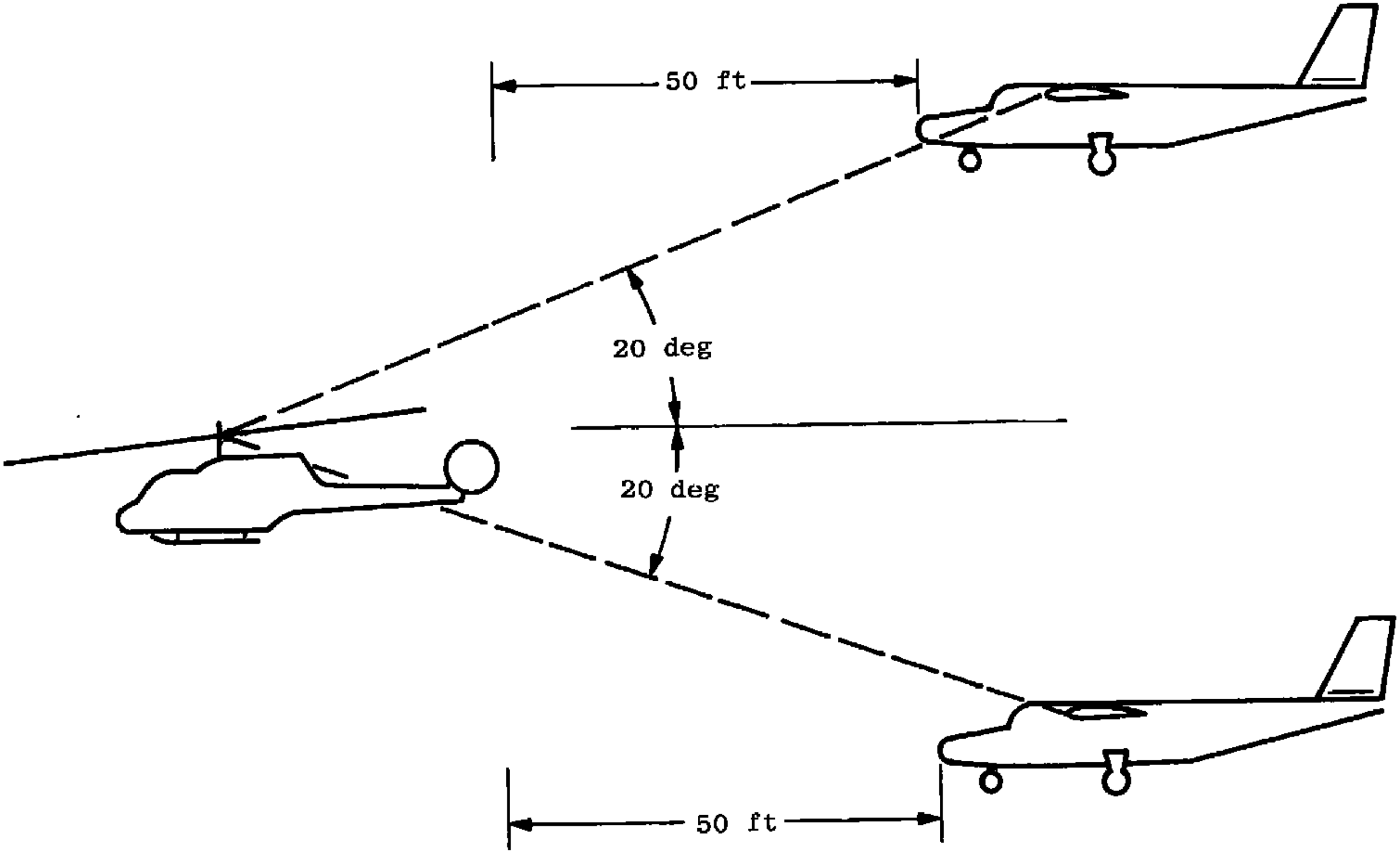
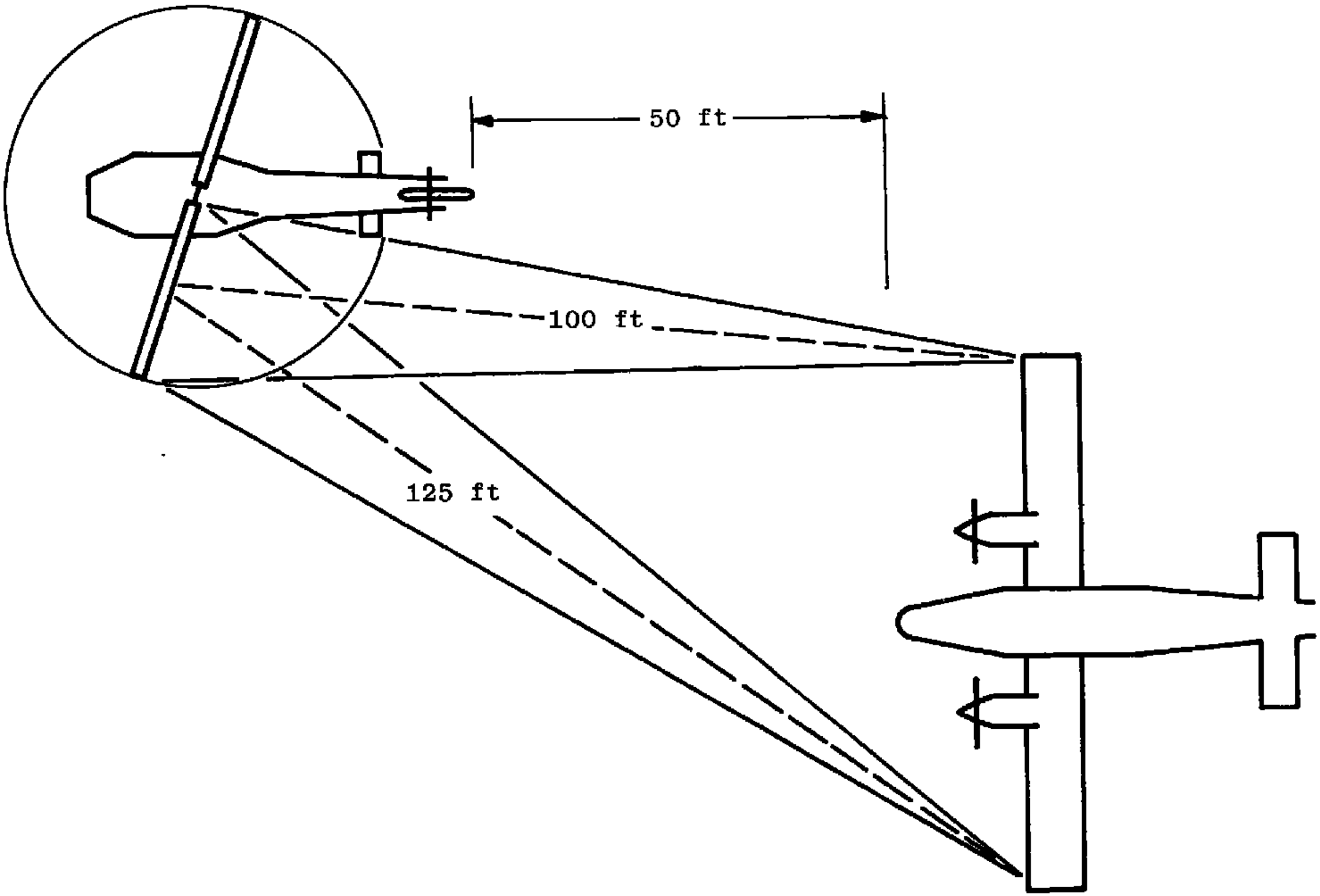


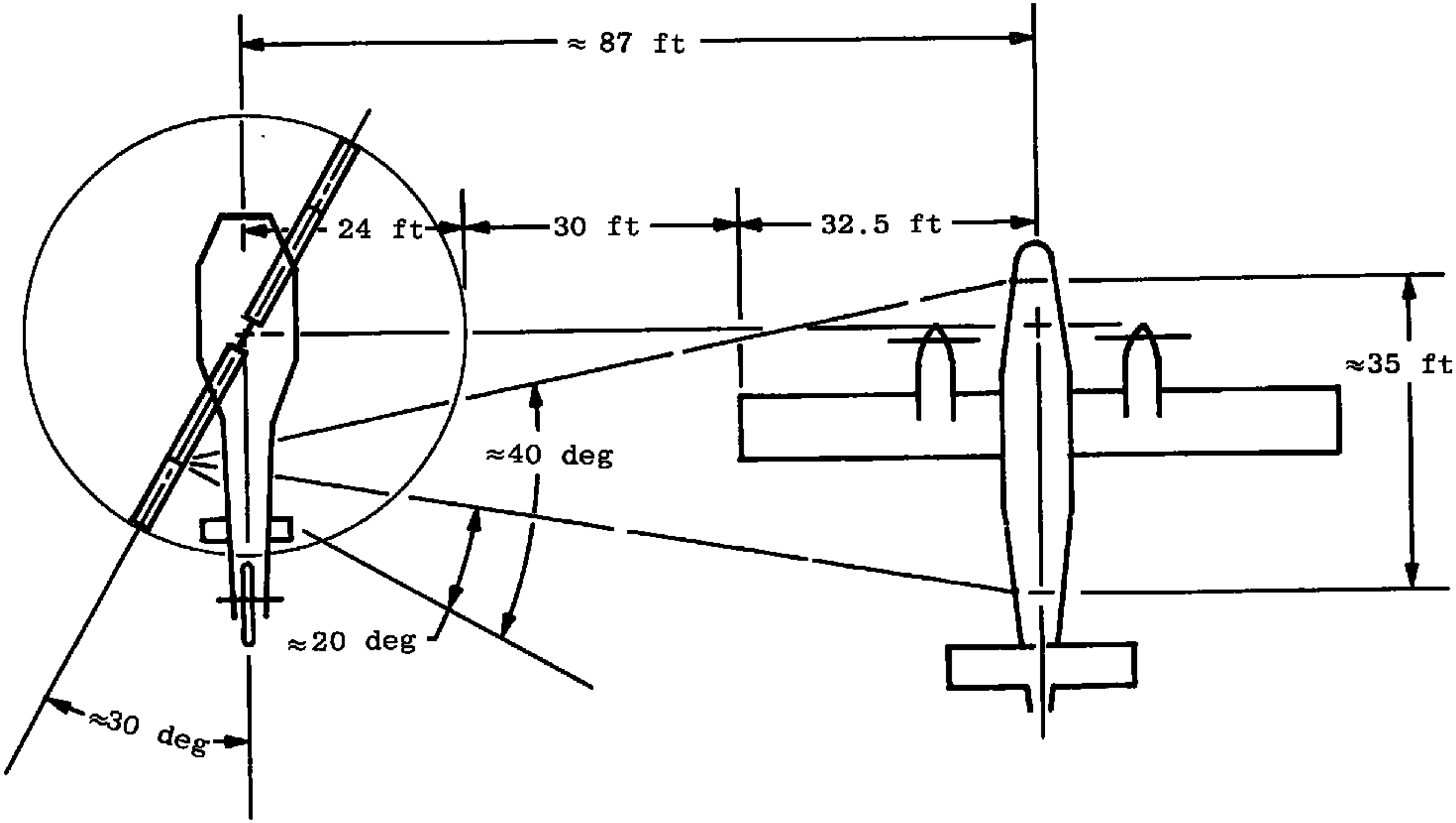

**Figure 2. Variation in maximum extension of ice forward of the blade leading edge.**




a. Side view
Figure 3. Flight formation for camera platform, concept No. 1.




**b. Top view**
**Figure 3. Concluded.**




Note: The camera platform (NASA LeRC DHC-6 Twin Otter) is approximately 10 ft below the test helicopter.

**Figure 4. Flight formation for camera platfor, concept No. 2.**


**Figure 5. NASA-LeRC DHC-6 Twin Otter.**

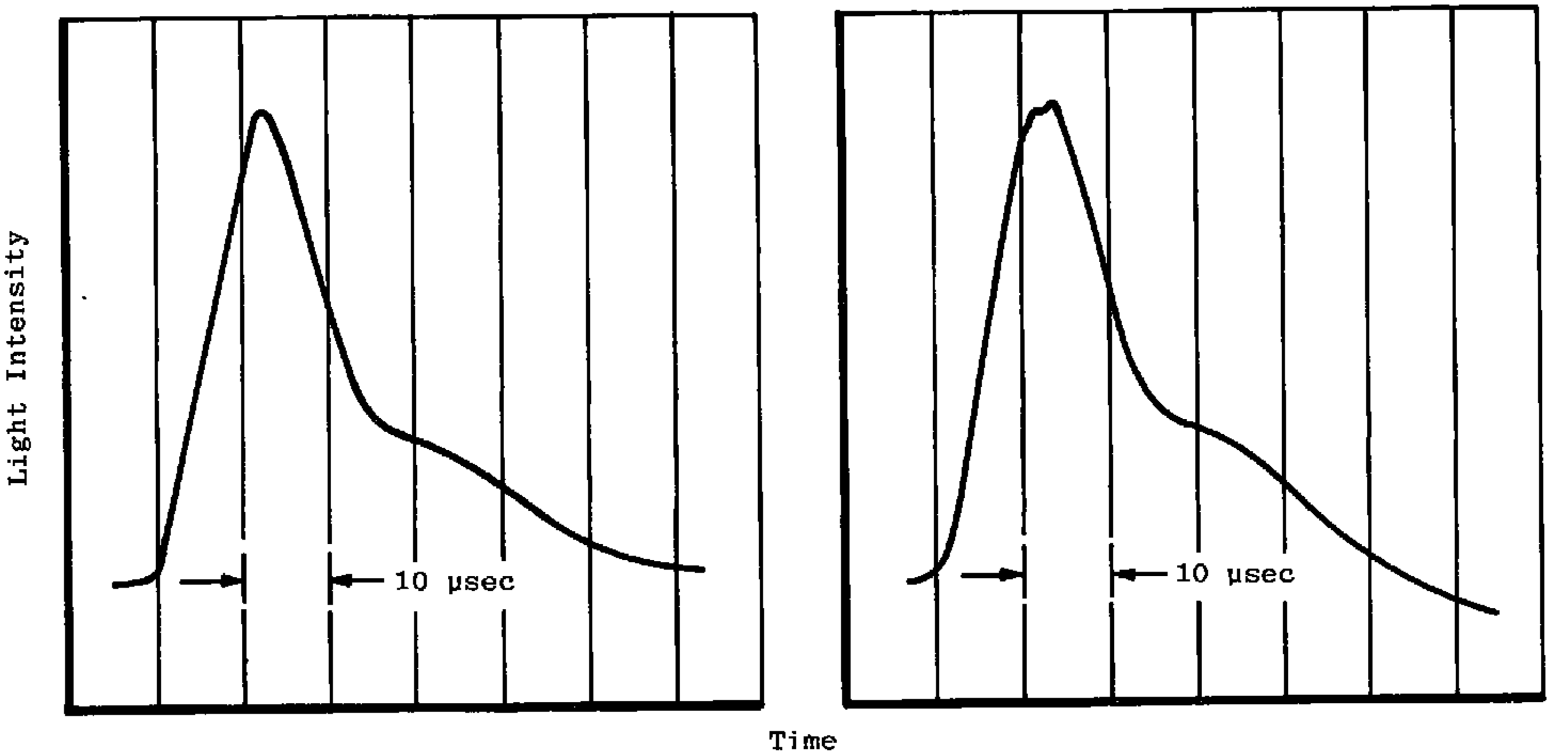



**Figure 6. Flash light-pulse calibration.**

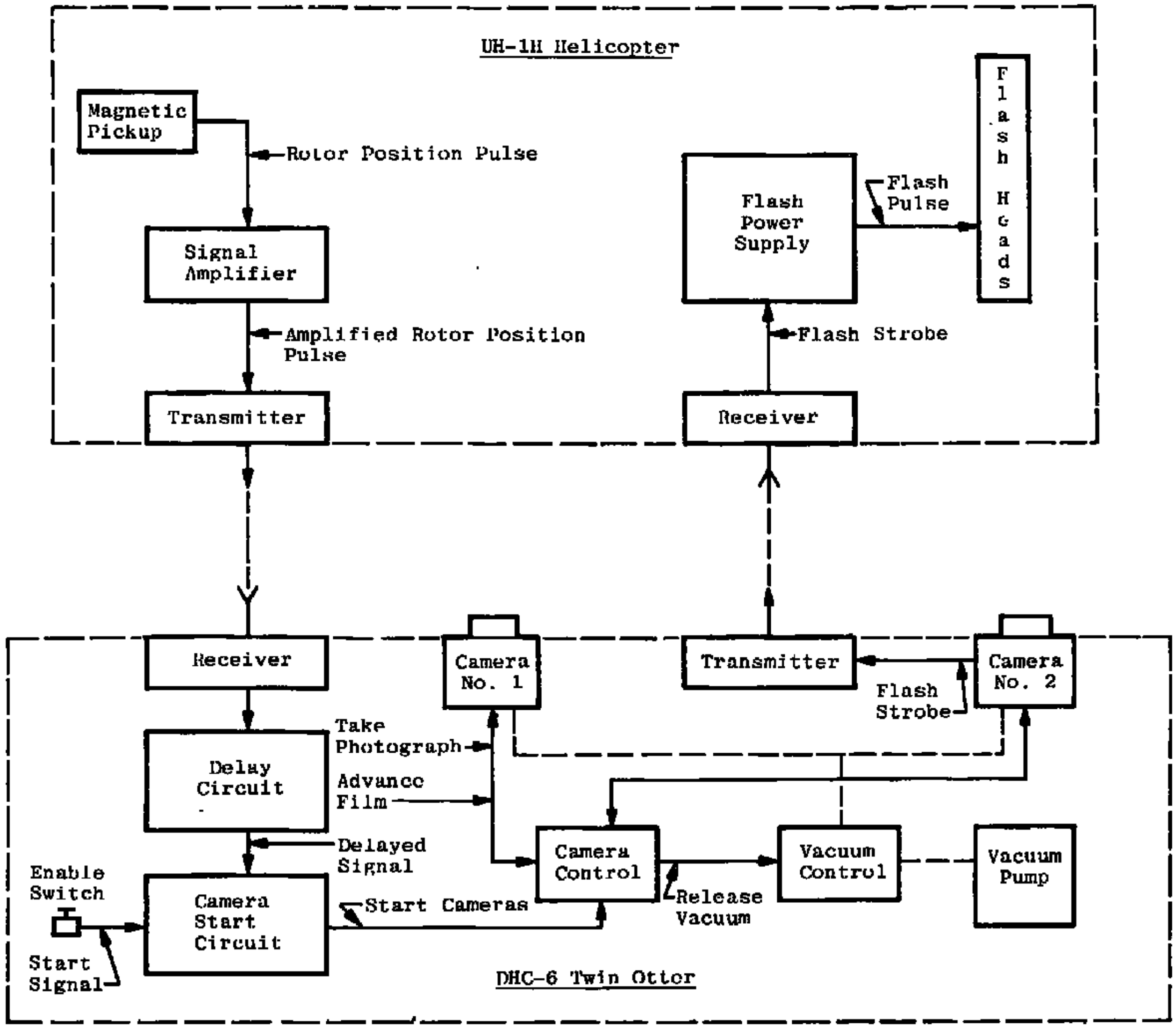



Figure 7. Initial control circuit diagram.

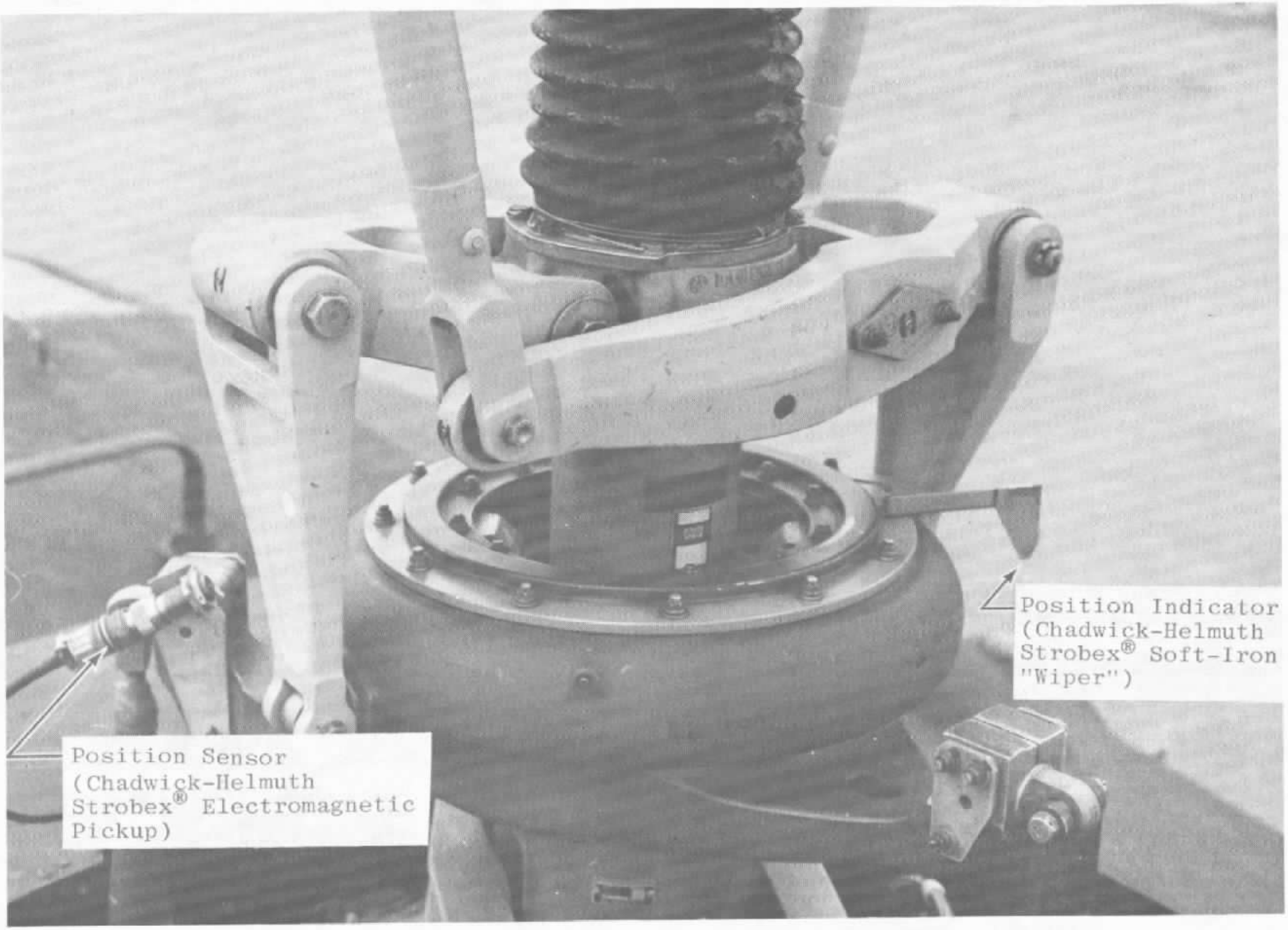



**Figure 8. Rotor position indicator installation.**

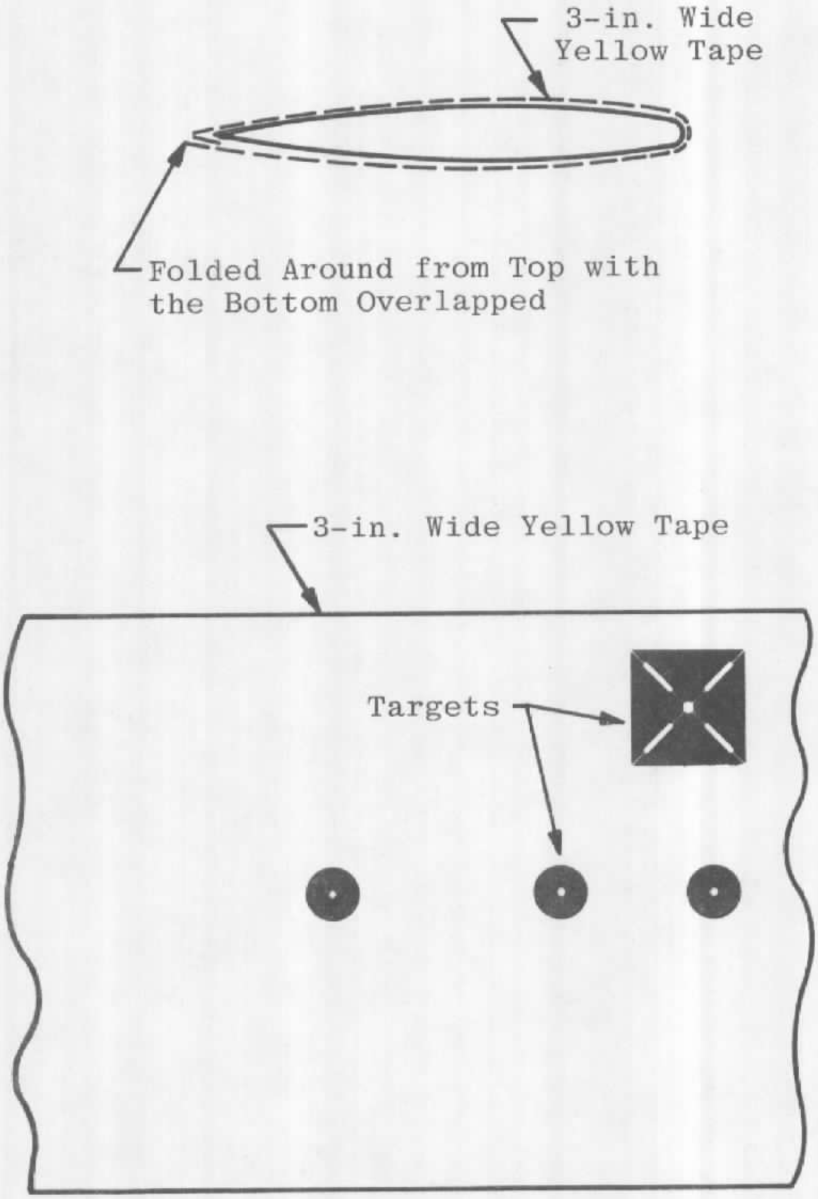
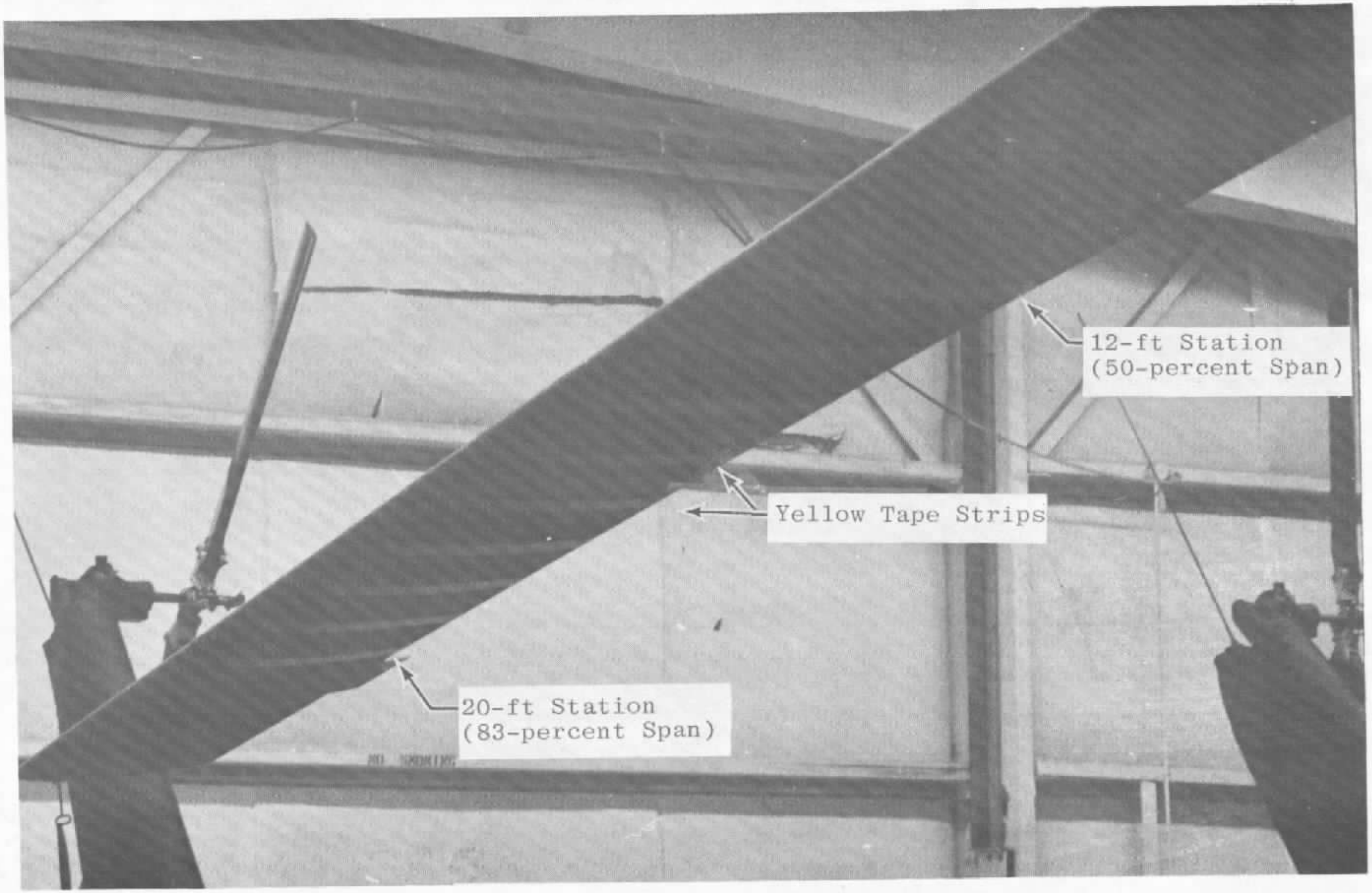
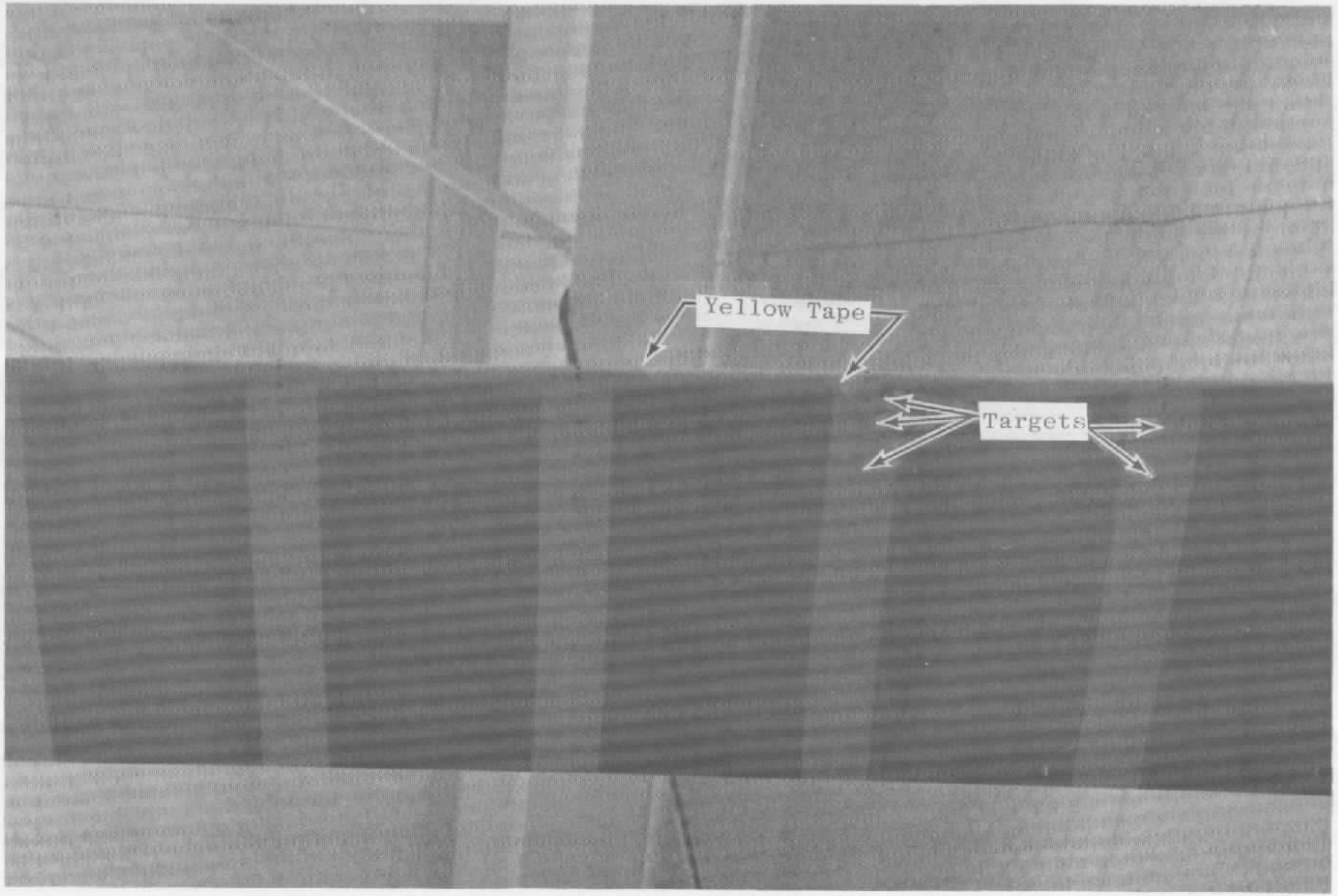


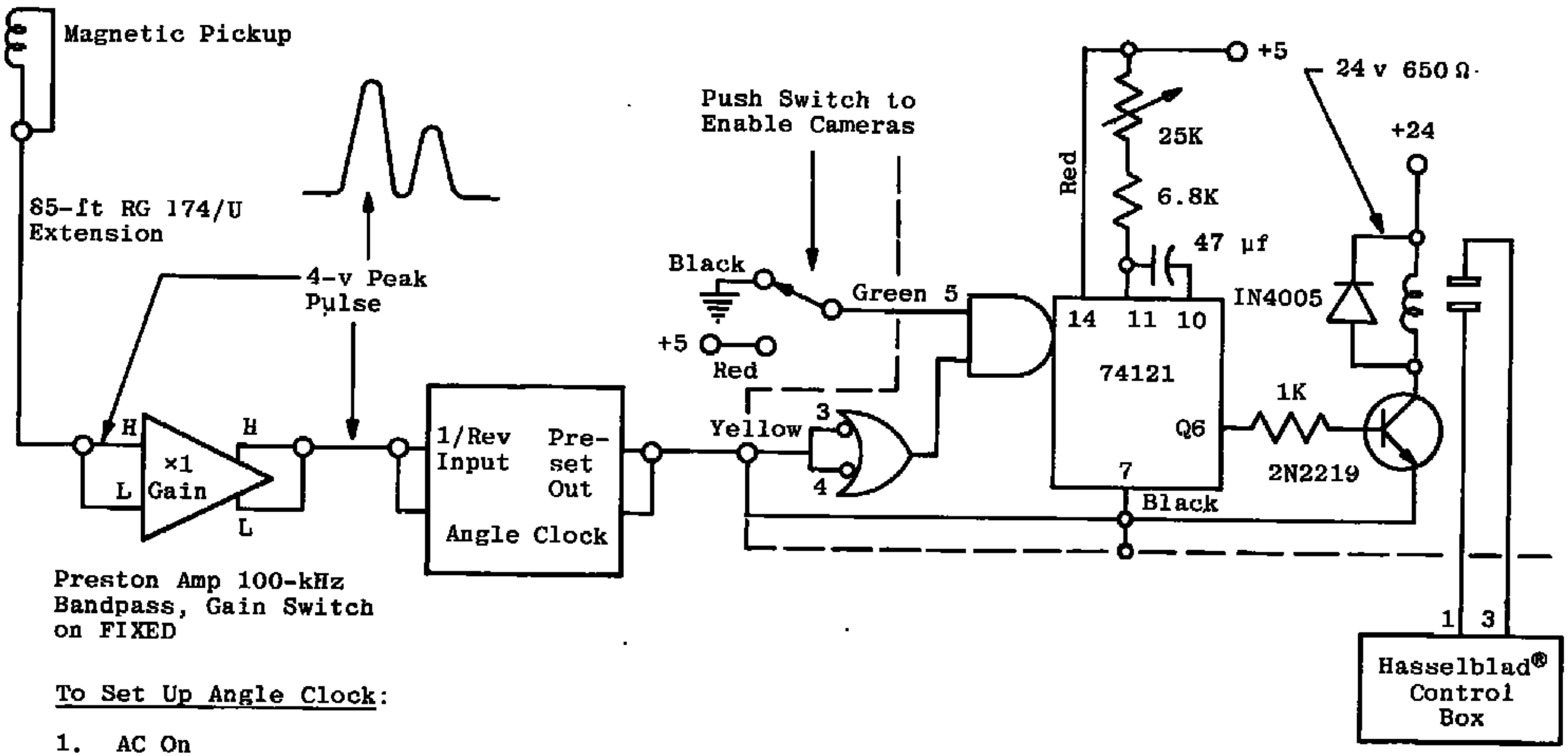

**Figure 9. Rotor marking targets and installation.**




**a. Spanwise station markings**
**Figure 10. Rotor marking strips and targets.**




**b. Analysis targets**
**Figure 10. Concluded.**

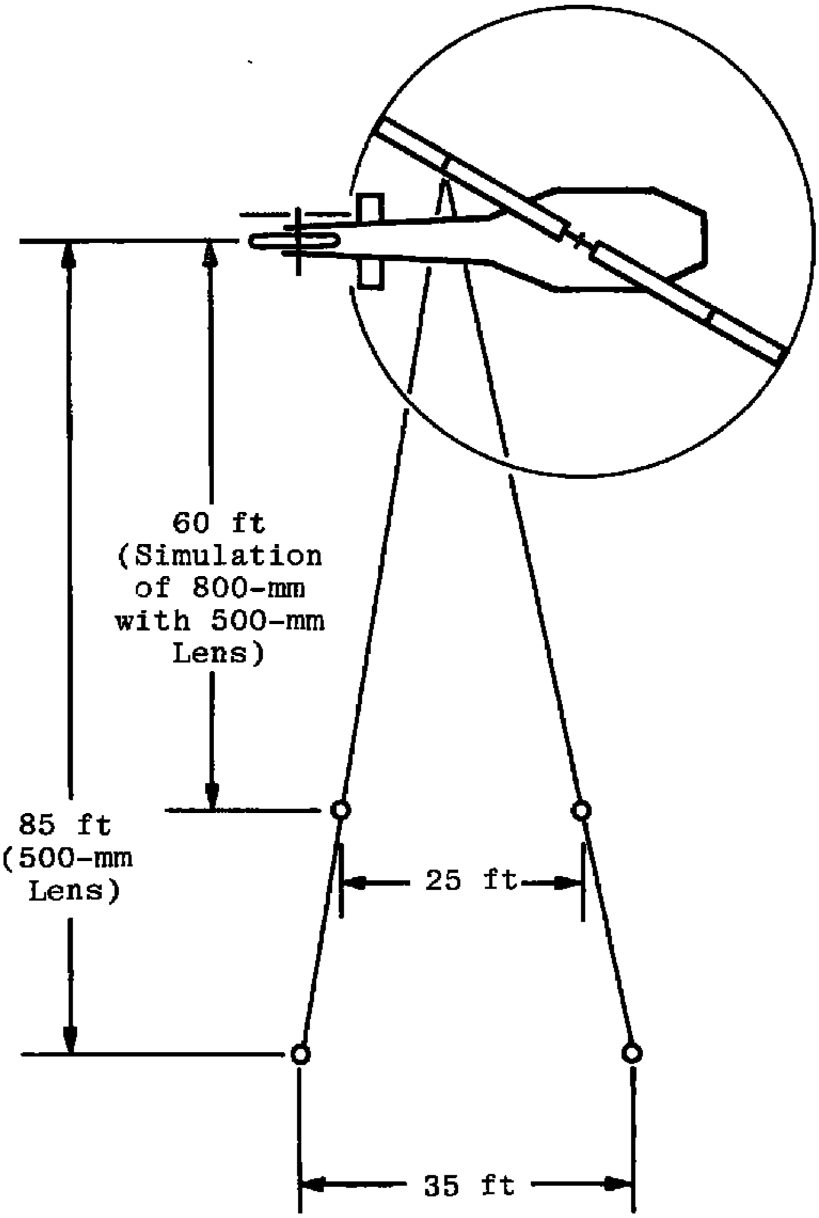



To Set Up Angle Clock:

1. AC On
2. Mode Switch to HOLD
3. Push Set Button Twice
4. Mode Switch to TRACK

Now any degree of angle lag can be dialed into the thumbwheel switches.

**Figure 11. Camera/blade synchronization hookup and operational instructions.**




Note: Camera lookup angle at the 35-ft position was approximately 10 deg.

**Figure 12. Helicopter/camera orientation during ground test.**


**Figure 13. Test helicopter and flash system.**

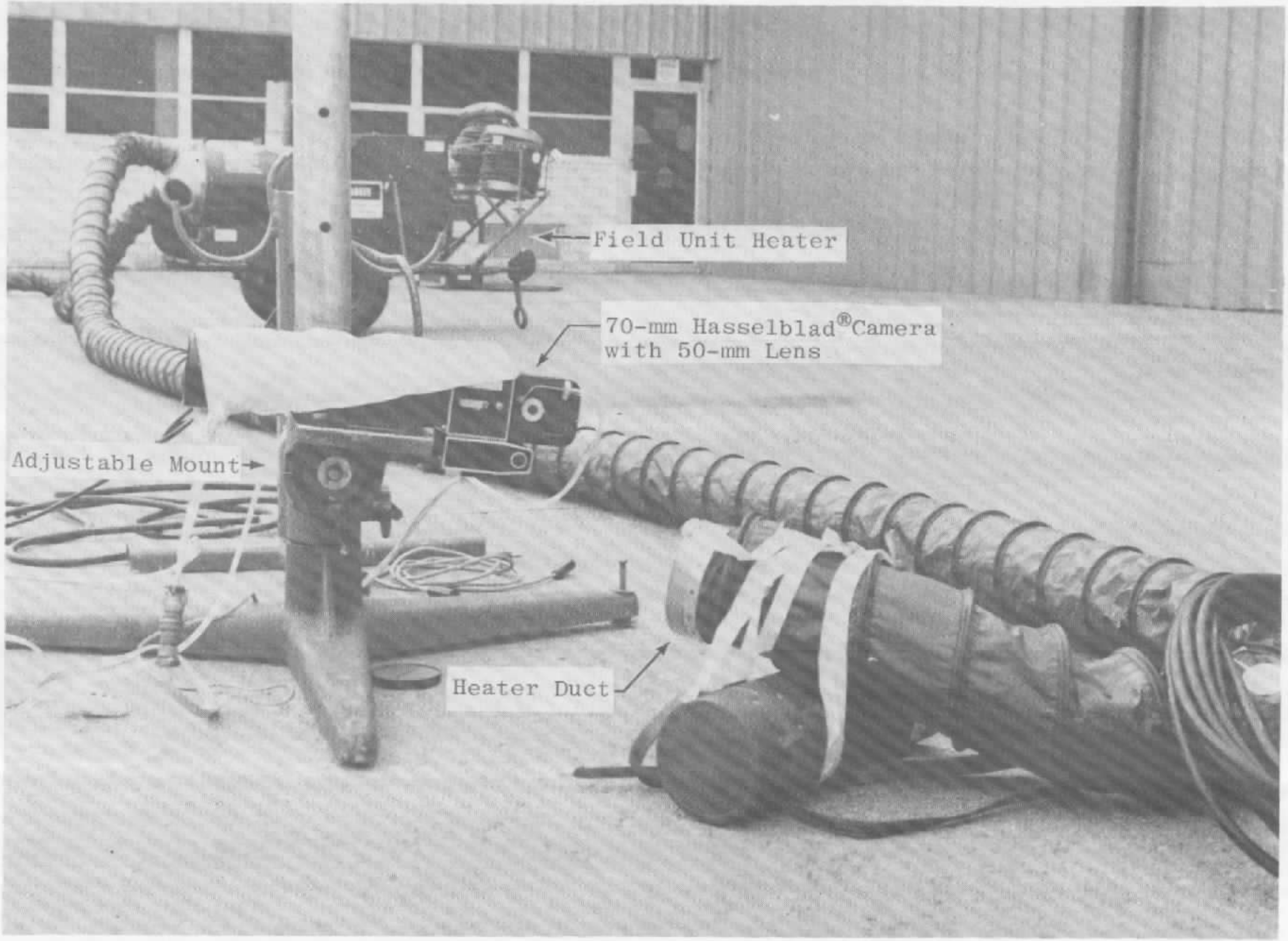



**Figure 14. Camera test installation and heating system.**

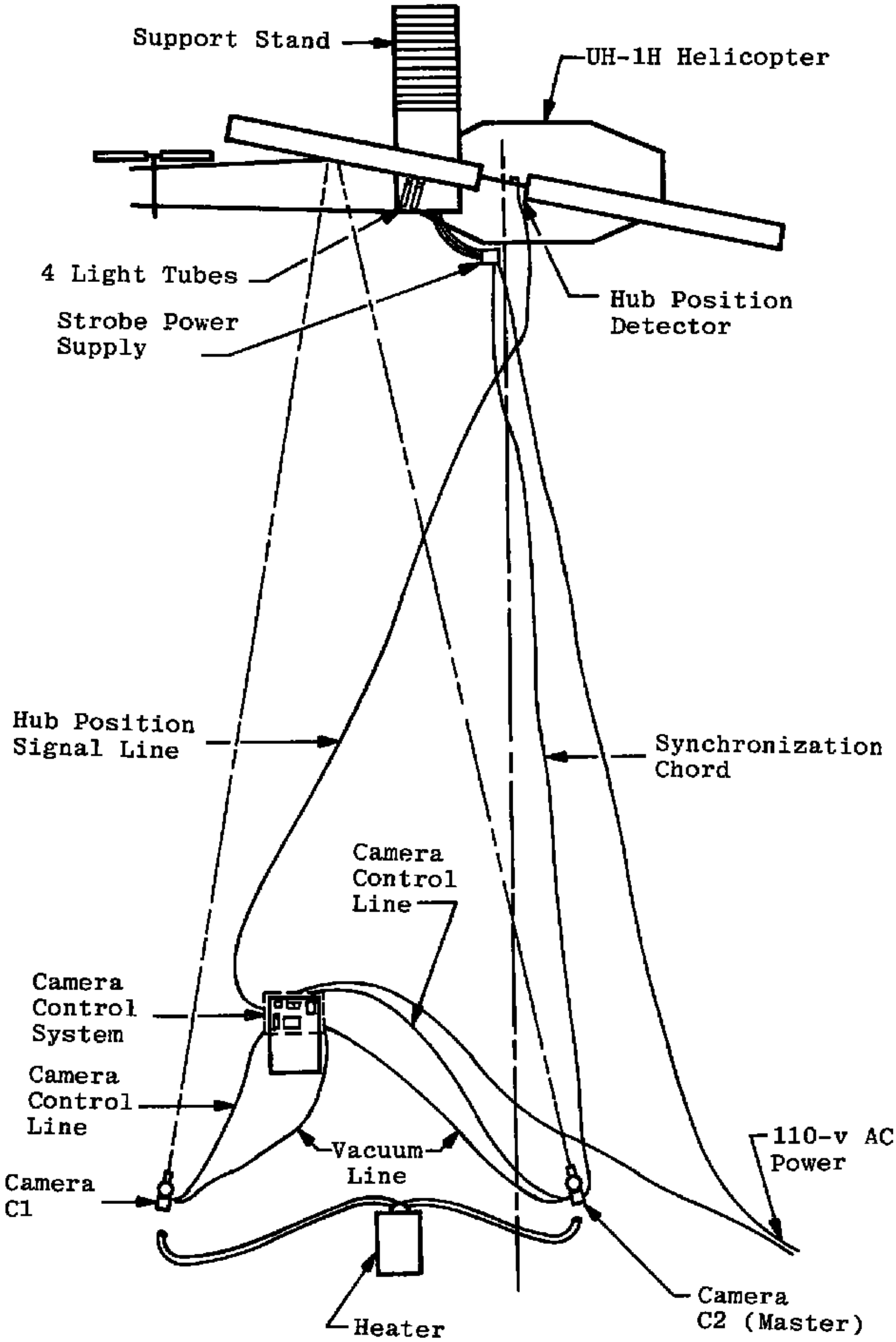



Figure 15. Layout of complete ground test system.

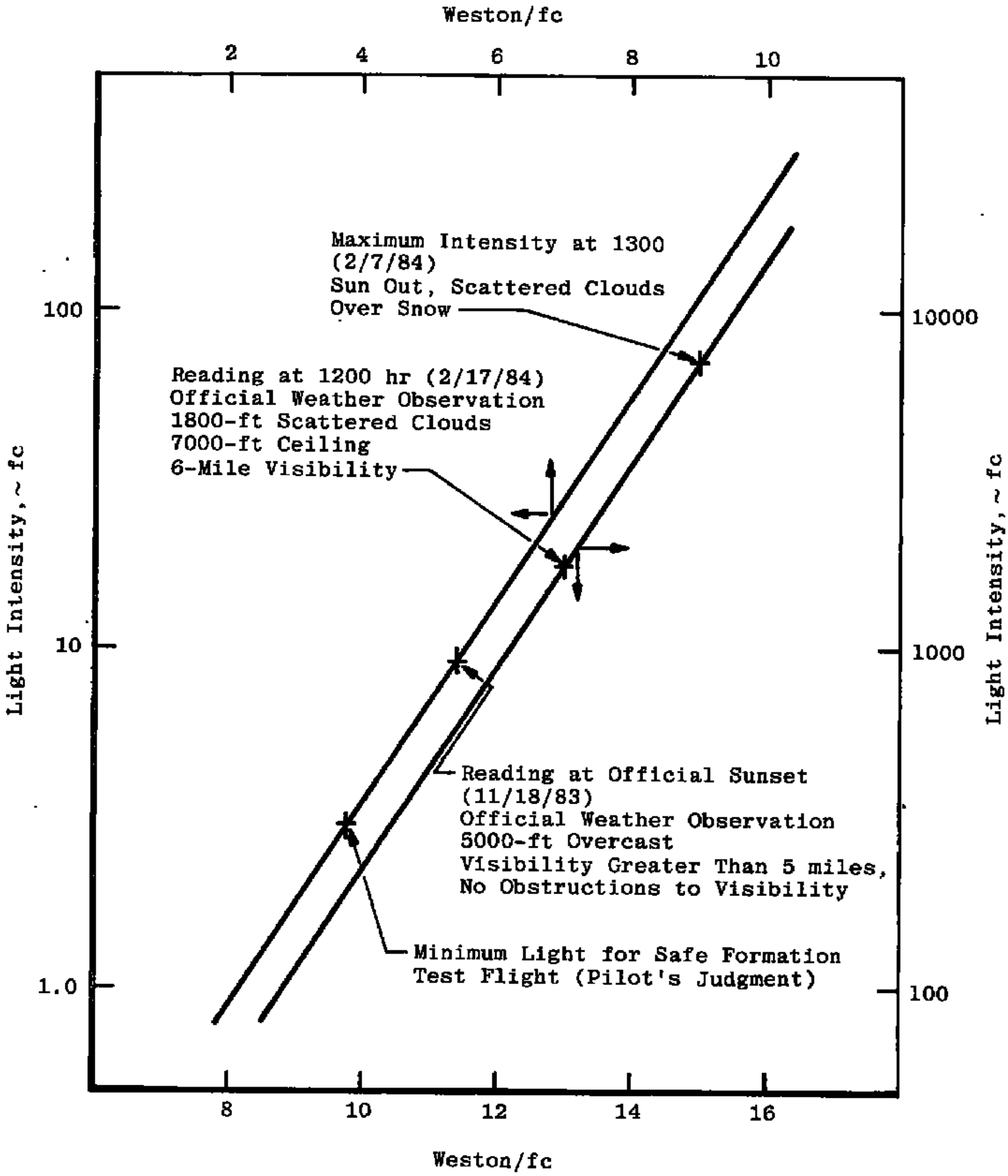
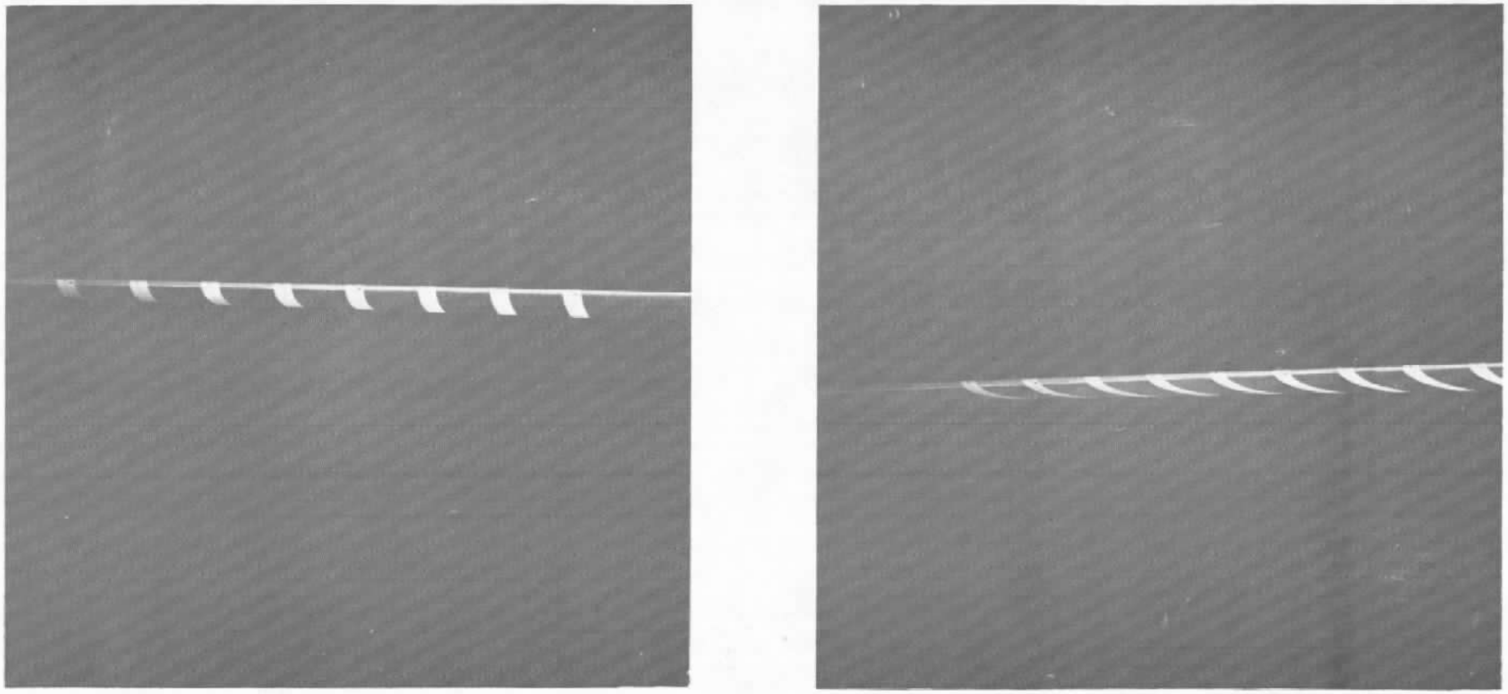
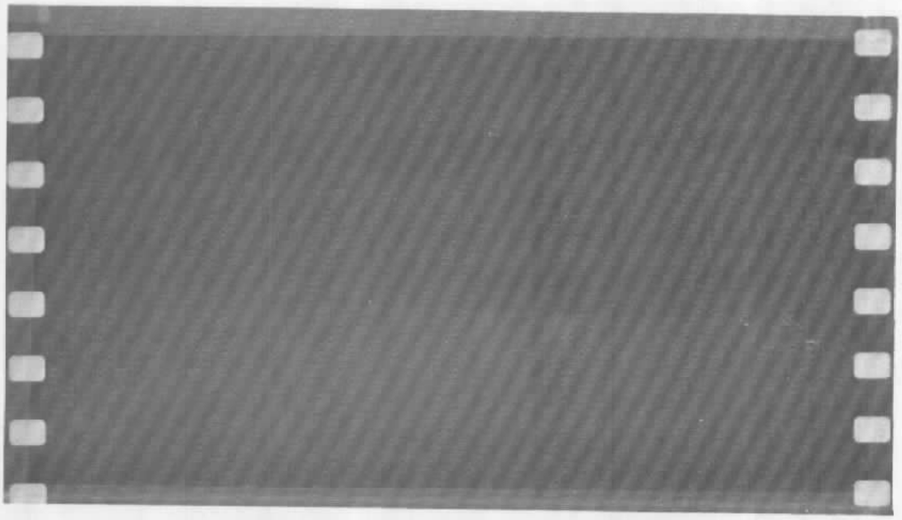



**Figure 16. Weston/fc conversion chart.**

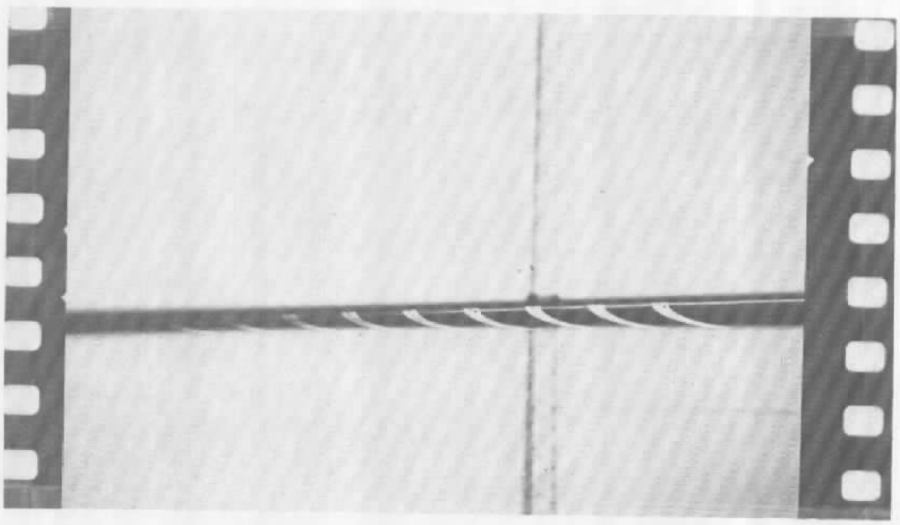


Left Camera (C1) Right Camera (C2)

**Figure 17. Typical stereophotographic pair from ground test.**

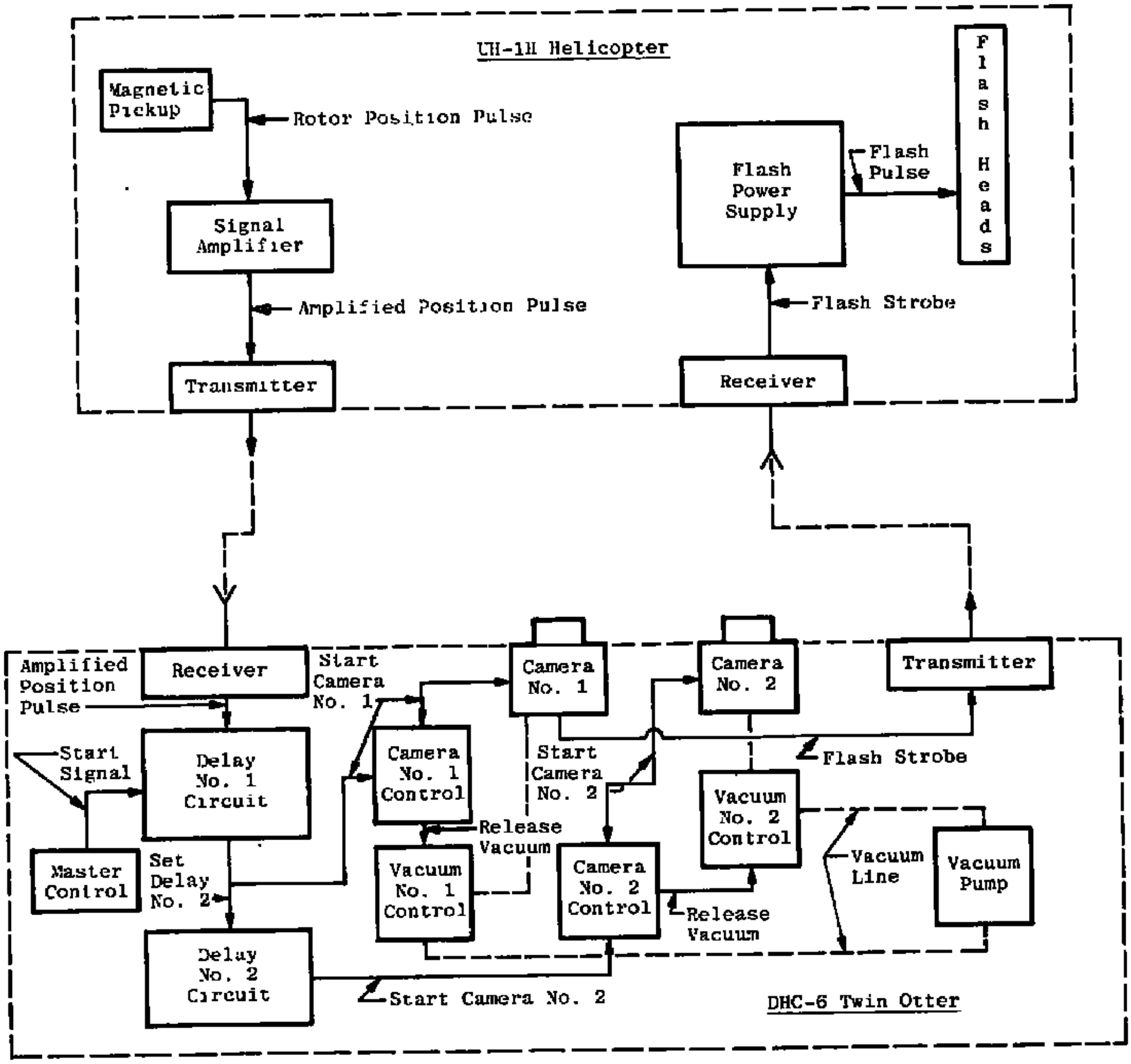


Shutter Speed = 1/30 sec
Ambient Light Intensity ≈ 75 fc



Shutter Speed = 1/500 sec
Ambient Light Intensity ≈ 1160 fc

**Figure 18. Examples of photo quality at two shutter speeds and ambient light intensities.**




Notes:

1. Delay No. 1 is equal to the time it takes for the blade to rotate from the detector position to the required position for the stereophotographs, minus the time it takes to open the shutter to full open of the slowest camera (Camera No. 1).
2. Delay No. 2 is equal to the difference in the speed of the shutter mechanical systems of the two cameras.

**Figure 19. Final control circuit concept.**

## Table 1. Test Log

| Date | Exposure Number | Camera Position | | Flash Pulse | Ambient Light | | Background | | Blade Angle | Camera Setting | | Remarks: |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Distance, ft | Separation, ft | Number of Capacitors | Meter | fc | Time | Weather | | Shutter Speed, sec | f/Stop | |
| 11/17/83 | 1 | 85 | 35 | 1 | --- | --- | Night | Clear | 0530 | 1/30 | 8 | (1) Left camera was C1. |
| Thursday (P.M.) | 2 | | | | --- | --- | | | | | | (2) Right camera was C2 |
| | 3 | | | | --- | --- | | | | | | and was used as master. |
| | 4 | | | | --- | --- | | | | | ↓ | (3) Cameras were 16.5 |
| | 5 | | | | --- | --- | | | | | 16 | in. off the ground. |
| | 6 | | | | --- | --- | | | ↓ | | | |
| | 7 | | | | --- | --- | | | Variable | | | (4) Film speed was 64. |
| | 8 | | | | --- | --- | | | | | | |
| | 9 | | | | --- | --- | | | ↓ | | | |
| | 10* | | | | --- | --- | | | 0700 | | | |
| | 11 | | | | --- | --- | | | | | ↓ | |
| | 12* | | | | --- | --- | | | | | 8 | |
| | 13 | | | ↓ | --- | --- | | | ↓ | | | |
| | 14 | | | 4 | --- | --- | | | 0600 | | | |
| | 15* | | | | --- | --- | | | 0700 | | ↓ | |
| | 16* | | | | --- | --- | | | | | 11 | |
| | 17 | | | | --- | --- | | | | | 11 | |
| | 18* | | | | --- | --- | | | | | 22 | |
| ↓ | 19 | ↓ | ↓ | ↓ | --- | --- | ↓ | ↓ | ↓ | ↓ | 22 | |

*Indicates exposures that were analyzed on the analytical stereocompiler.

## Table 1. Continued

| Date | Exposure Number | Camera Position | | Flash Pulse | Ambient Light | | Background | | Blade Angle | Camera Setting | | Remarks: |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Distance, ft | Separation, ft | Number of Capacitors | Meter | fc | Time | Weather | | Shutter Speed, sec | f/Stop | |
| 11/18/83 | 1 | 85 | 35 | 4 | 8.2 | 64 | 0728 | Clear | 0400 | 1/30 | 8 | (1) Vacuum OFF |
| Friday (A.M.) | 2 | | | | 8.4 | 73 | 0729 | | 0400 | | | (2) Vacuum OFF |
| | 3* | | | | | | 0729 | | 0700 | | | (3) Film speed was 64. |
| | 4 | | | | | | 0730 | | 0630 | | | |
| | 5 | | | | | | 0731 | | 0800 | | | |
| | 6* | | | | | | 0733 | | 0700 | 1/500 | | |
| | 7 | | | | 8.6 | 85 | 0734 | | | 1/500 | | |
| | 8* | | | | 10.4 | 290 | 0737 | | | 1/30 | | |
| | 9 | | | | 10.5 | 310 | 0737 | | | 1/30 | | |
| | 10* | | | | | | 0738 | | | 1/500 | | |
| | 11 | | | | | | 0739 | | | 1/500 | | |
| | 12* | | | | 12.0 | 880 | 0741 | | | 1/60 | | |
| | 13 | | | | | | 0742 | | | 1/60 | | |
| | 14* | | | | | | 0745 | | | 1/30 | | |
| | 15 | | | | | | 0745 | | | 1/30 | | |
| | 16* | | | | 12.4 | 1160 | 0747 | | | 1/500 | | (4) Vacuum ON |
| | 17 | | | | 12.4 | 1160 | 0748 | | | 1/500 | | (5) Vacuum ON |
| | 18* | | | | 13.3 | 2200 | 0754 | | 0600 | 1/30 | | |
| | 19 | | | | 13.3 | 2200 | 0755 | | 0600 | 1/30 | | |

*Indicates exposures that were analyzed on the analytical stereocompiler.

## Table 1. Continued

| Date | Exposure Number | Camera Position | | Flash Pulse | Ambient Light | | Background | | Blade Angle | Camera Setting | | Remarks: |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Distance, ft | Separation, ft | Number of Capacitors | Meter | fc | Time | Weather | | Shutter Speed, sec | f/Stop | |
| 11/18/83 | 1* | 85 | 35 | 4 | 8.4 | 73 | 1637 | 5000 ft | 0700 | 1/500 | 8 | (1) UH-1H, Eng. rpm = 6600, Rotor rpm = 324 |
| Friday (P.M.) | 2 | | | | 8.4 | 73 | 1637 | Overcast | 0600 | | | (2) Flat Pitch, 11 psi Torque |
| | 3 | | | | 8.2 | 64 | 1638 | | 0700 | | | **(3) Amb. Conditions:** Temp = −10 to 0°C |
| | 4 | | | | 8.0 | 55 | 1641 | | 0700 | 1/60 | | Press.Altitude = 840 ft |
| | 5* | | | | 7.9 | 52 | 1642 | | 0730 | 1/60 | | Wind = 10 Knots |
| | 6* | | | | 7.9 | 52 | 1644 | | 0700 | 1/30 | | (4) Anterior Collision Lights OFF |
| | 7 | | | | 7.8 | 48 | 1645 | | | 1/30 | | (5) Position Lights on BRIGHT |
| | 8 | | | | 7.5 | 39 | 1647 | | | 1/60 | | (6) Top White Position Lights OFF |
| | 9 | | | | 7.3 | 34 | 1648 | | 0730 | 1/60 | | |
| | 10 | | | | 7.0 | 28 | 1650 | | 0700 | 1/30 | | (7) Film speed was 64. |
| | 11* | | | | 7.0 | 28 | 1651 | | 0730 | 1/30 | | |
| | 12* | | | | 6.8 | 24 | 1652 | | 0700 | 1/60 | | (8) Pilot could see reflec- |
| | 13 | | | | 6.5 | 20 | 1653 | | 0730 | 1/60 | | tion on front blade. |
| | 14 | | | | 6.4 | 18.5 | 1655 | | 0700 | 1/30 | | |
| | 15* | | | | 6.2 | 16 | 1656 | | 0730 | 1/30 | | |
| | 16* | | | | 5.9 | 13 | 1658 | | 0700 | 1/60 | | |
| | 17 | | | | 5.9 | 13 | 1659 | | | 1/60 | | |
| | 18 | | | | 5.5 | 10 | 1700 | | | 1/30 | | |
| | 19 | | | | 4.9 | 6.6 | 1701 | | | 1/30 | | |
| | 20 | | | | 5.3 | 8.6 | 1704 | | 0730 | 1/60 | | |
| | 21 | | | | 5.4 | 9.2 | 1705 | | | 1/60 | | (9) Official Sunset |
| | 22 | | | | 5.3 | 8.6 | 1706 | | | 1/30 | | |
| | 23* | | | | 5.0 | 7.0 | 1706 | | | 1/30 | | |
| | 24* | | | | 5.1 | 7.5 | 1707 | | | 1/60 | | |
| | 25 | | | | 5.1 | 7.5 | 1708 | | | 1/60 | | |

*Indicates exposures that were analyzed on the analytical stereocompiler.

## Table 1. Concluded

| Date | Exposure Number | Camera Position | | Flash Pulse | Ambient Light | | Background | | Blade Angle | Camera Setting | | Remarks: |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Distance, ft | Separation, ft | Number of Capacitors | Meter | fc | Time | Weather | | Shutter Speed, sec | f/Stop | |
| 11/18/83 | 26 | 85 | 35 | 4 | 5.0 | 7.0 | 1710 | 5000 ft | 0715 | 1/30 | 8 | |
| Friday (P.M.) | 27 | | | | 4.9 | 6.6 | 1711 | Overcast | | 1/30 | | |
| | 28 | | | | 4.6 | 5.3 | 1712 | | | 1/60 | | |
| | 29 | | | | 4.4 | 4.6 | 1713 | | | 1/60 | | |
| | 30 | | | | 4.1 | 3.8 | 1714 | | | 1/30 | | |
| | 31* | | | | 4.0 | 3.5 | 1715 | | | 1/30 | | |
| | 32* | | | | 4.0 | 3.5 | 1716 | | | 1/60 | | |
| | 33 | | | | 3.8 | 3.0 | 1716 | | | 1/60 | | (1) Minimum Light for Safe |
| | 34 | | | | 3.4 | 2.3 | 1717 | | | 1/30 | | Flight Testing; Position |
| | 35* | | | | 3.0 | 1.8 | 1718 | | | 1/30 | | Lights Turned OFF |
| | 36* | | | | 3.0 | 1.8 | 1720 | | | 1/60 | | |
| | 37 | | | | 2.5 | 1.25 | 1721 | | | 1/60 | | |
| | 38 | | | | | | 1722 | | | 1/30 | | |
| | 39 | | | | | | 1723 | | | 1/30 | | |
| | 40 | | | | 2.0 | 0.88 | 1724 | | | 1/60 | | |
| | 41 | | | | 2.0 | 0.88 | 1725 | | | 1/60 | | |
| | 42 | | | | | | | | | | | (2) Blank |
| | 43 | | | | | | | | | | | (3) Blank |
| | 44 | | | | | | | | | | | (4) Blank |
| | 45 | | | | | | | | | | | (5) Blank |
| | 46* | 60 | 25 | | Dark | 0.88 | 1810 | | 0700 | 1/30 | 8 | (6) Total Darkness at 1745 hrs |
| | 47 | | | | | | 1810 | | | | | |
| | 48 | | | | | | 1811 | | | | | |
| | 49 | | | | | | 1812 | | | | | |

*Indicates exposures that were analyzed on the analytical stereocompiler.

Table 2. Summary of the Test Evaluation

| Date | Exp. No. | Comments: |
|---|---|---|
| 11/17/83 (Night) | 10 | Not readable. |
| | 12 | Very difficult to read, possibly could read at first 2 strips since "x" in square target is slightly visible. |
| | 15 | Could read the first 5 strips with a fair degree of confidence; left camera shows very little motion; right camera has visible motion but should give fair data. |
| | 16 | Could read the first 4 strips with a fair degree of confidence; motion the same as No. 15; problem outside of strip No. 4 is lack of light. |
| | 18 | Not readable. |
| 11/18/83 (A.M.) | 3 | Motion the same as No. 15 (11/17/83), based on left camera (which was not looking into sun like right camera) data could probably be read out to the 5th strip; care should be taken to have sun to back of cameras. |
| | 6 | Right camera only (one looking into sun); the motion has been very nearly stopped. It compares with the left camera at 1/30 sec; could read out to the 4th strip with good results; could probably get usable data out to the 5th strip. |
| | 8 | Right camera is unreadable (into sun); left camera could be read out to the 4th strip with great difficulty. |
| | 10 | Same as No. 6. |
| | 12 | Significant difference between 1/30 sec (No. 3) and 1/60 sec (No. 12) in both motion and visibility; however, still no comparison to 1/500 sec (No. 6) in readability. Left camera could probably be read out to the 5th strip with good quality. Right camera (into sun) could read first 2 strips. |
| | 14 | Both cameras unusable. |
| | 16 | Right camera only. Basically the same as No. 6, could possibly get usable data out to the 6th strip. |
| | 18 | Both cameras unusable. |

**Table 2. Concluded**

| Date | Exp. No. | Comments: |
|---|---|---|
| 11/18/83 (P.M.) | 1 | Same as No. 16 for 11/18/83 (A.M.). |
| | 5 | Right camera lost most of inside strip. This exposure doesn't seem to be sharp; would be difficult to read. |
| | 6 | Right camera is readable out to the 6th strip and could possibly give data out past that point. The left camera seems to have some blur; however, this is the camera that should be the least blurred. Basic exposure is good. |
| | 11 | Right camera is readable to the 4th strip. Left camera still appears to be blurred. |
| | 12 | Right camera is readable to the 6th strip. Left camera still appears to be out of focus. Basic exposure good. |
| | 15 | Right camera is good out to the 4th strip and readable to the 5th strip. Left camera still blurred. |
| | 16 | Basically same as No. 12. |
| | 23 | No change from No. 15. |
| | 24 | No change from No. 16. |
| | 31 | No change. |
| | 32 | No change. |
| | 35 | No change. |
| | 36 | No change. |
| | 46 | Left camera appears to be completely out of focus now. Right camera cannot be read any farther out from the hub than at the 85-ft distance. Only 4 strips could be used. |